THE RELATIONSHIP BETWEEN INHALANT USE AND ADOLESCENT GATEWAY DRUG USE SEQUENCING: A LATENT TRANSITION ANALYSIS

Erik Crankshaw

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Approved by:

Advisor: Susan Ennett

Reader: Vangie Foshee

Reader: Kurt Ribisl

Reader: Linda Collins

Reader: Antonio Morgan-Lopez

ABSTRACT

ERIK CRANKSHAW: The Relationship between Inhalant Use and Adolescent Gateway Drug Use Sequencing: A Latent Transition Analysis

(Under the direction of Susan Ennett)

Introduction: Inhalant use is the most prevalent form of illicit drug use among young (<8th grade) adolescents in the United States and inhalants share several characteristics with gateway drugs (alcohol, tobacco, and marijuana). The purpose of this study was to determine whether, and if so, how the gateway hypothesis of drug use sequencing could be expanded to include inhalants for African American and white adolescents. In addition, the study examined whether various psychosocial characteristics could account for the transition from inhalant use to a later stage of drug use.

Methods: Data were from a panel study on adolescents from 13 schools in three counties in North Carolina. The study focused on transitions from 6th to 7th grade (N = 1,630) and from 7th to 8th grade (N = 3,344), and the analyses were conducted separately for African American males, African American females, white males, and white females to assess race and gender differences in drug use sequencing. Latent transition analysis (LTA) was used to identify models of drug use sequencing and to estimate drug use prevalence and the probabilities of transitioning from one drug use stage to another. Formal criteria for establishing gateway relationships were examined to determine whether inhalant use was operating as a gateway to other drug use.

Results: For white males and African American males and females, there was no evidence that inhalants serve a gateway role. However, inhalant use preceded and increased

the probability of marijuana use for a significant number of white females at both transition periods; formal criteria were met supporting inhalant use as a gateway to marijuana use for white females transitioning from 6th to 7th grade, and the probability of transitioning from inhalant use to marijuana use remained significant after controlling for a variety of psychosocial characteristics.

Conclusions: This study was the first to formally evaluate the relationship between inhalant use and gateway drug use. The finding that inhalants appear to play an important role in gateway drug use sequencing for white females, coupled with findings from recent studies that suggest inhalant use has increased among female adolescents, supports an increased focus on inhalant use.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	alcohol and cigarettes
ACI	alcohol, cigarettes, and inhalants
ACIM	alcohol, cigarettes, inhalants, and marijuana
AIC	Akaike information criterion
ALT-YRBS	Alternative High School Youth Risk Behavior Survey
BIC	Bayesian information criterion
CDC	Centers for Disease Control and Prevention
DA	data augmentation
DSM-IV	Diagnostic and Statistical Manual of Mental Disorders, 4th Edition
EM	expectation maximization
IRB	institutional review board
LTA	latent transition analysis
MTF	Monitoring the Future
NHSDA	National Household Survey on Drug Abuse
NIDA	National Institute on Drug Abuse
NSDUH	National Survey on Drug Use and Health
SAMHSA	Substance Abuse and Mental Health Services Administration
YRBS	Youth Risk Behavior Survey

CHAPTER 1

INTRODUCTION

1.1 Purpose

This dissertation investigates where and how inhalant use fits within drug use sequences and whether there is evidence for a gateway role for inhalant use in four adolescent groups: white males, white females, African American males, and African American females. Longitudinal data for white and African American adolescents collected from a general population sample of adolescents in grades 6 through 8 were used to examine the relationship between inhalants and the drugs commonly defined as gateway drugs: alcohol, tobacco (cigarettes), and marijuana.

1.2 Statement of the Problem

Inhalants are volatile substances that produce chemical vapors that can be inhaled to induce a psychoactive effect. Inhalants include a broad variety of widely available substances such as gasoline, glue, shoe polish, and spray paint. Although inhalants are not socially normative or marketed like alcohol and tobacco, they are easily accessible by youth, are often not perceived as harmful (Johnston, O'Malley, & Bachman, 1998), and are widely used by young adolescents (Substance Abuse and Mental Health Services Administration, 2008; Johnston, O'Malley, Bachman, & Schulenberg, 2005, 2007; Wu, Pilowsky, & Schlenger, 2004; Johnston, O'Malley, & Bachman, 2001).

It has been posited that inhalant use may operate as a gateway to later drug use (Edwards & Oetting, 1995). The idea that certain drugs serve as gateways to later illicit drug

use (Kandel, 1975, 2002; Kandel, Yamaguchi, & Chen, 1992) stems from the nearly ubiquitous finding that, among individuals who use, a standard drug use sequence is commonly followed: from the use of legal (for adults), widely available, and socially accepted and marketed substances (alcohol and tobacco), to marijuana, and then to other illicit drugs (e.g., cocaine, heroine). According to the gateway hypothesis, the use of a gateway drug significantly increases the probability of using a drug later in the sequence.

Inhalants may serve as a gateway to other drugs because of their pharmacological effects. Inhalants have been demonstrated to enhance dopamine activity in the brain's pleasure center in ways similar to other drugs of abuse (Riegel, Ali, & French, 2003), and people who use inhalants can develop cravings associated with dependence (Anthony, Warner, & Kessler, 1994; Howard, Cottler, Compton, & Ben-Abdallah, 2001). Given the wide availability of inhalants and the typical early age of first use, it is conceivable that inhalants may serve to introduce adolescents to the pleasurable sensations associated with increased dopamine activity, possibly increasing the likelihood of future drug-seeking behavior.

In support of this possibility, inhalant use has been identified as a key correlate of injection drug use and polydrug use (Dinwiddie, Reich, & Cloninger, 1991a; Schutz, Chilcoat, & Anthony, 1994; Johnson, Schutz, Anthony, & Ensminger, 1995). Inhalant use before age 16 has been shown to predict later heroin use after controlling for other risk factors (Johnson et al., 1995), and use before age 18 has been associated with later illicit drug use and binge drinking (Bennett, Walters, Miller, & Woodall, 2000; Sakai, Hall, Mikulich-Gilbertson, & Crowley, 2004).

Together, the findings concerning inhalants' pharmacological effects and association with illicit drugs suggest a potentially important gateway role for inhalants in adolescent drug use sequencing. But critics of the gateway hypothesis suggest that factors such as drug availability, perceived peer drug use, and an underlying proclivity to engage in problematic or sensation-seeking behaviors better explain the sequencing of drug use in adolescents and that the standard gateway pattern being observed is actually an artifact representing drug availability, personality attributes, and social norms (Morral, McCaffrey, & Paddock, 2002; Golub & Johnson, 2002a; Agrawal, Neale, Prescott, & Kendler, 2004b; Tarter, Vanyukov, Kirisci, Reynolds, & Clark, 2006).

In order to evaluate the potential gateway role of inhalants, it is necessary to demonstrate both that inhalant use significantly increases the probability of using other drugs and that the relationship between inhalant use and drug use transitions remains significant after accounting for factors such as perceived drug availability, perceived peer drug use and attitudes, sensation seeking and delinquency, academic achievement, and parental (mother's) disapproval of drug use.

1.3 Study Research Questions

This dissertation investigated the role inhalants play in adolescent gateway drug use sequencing. To this end, the following research questions were examined:

1. *Can the gateway hypothesis be extended to include inhalants for African American and white, male and female adolescents in grades 6 through 8?*
2. *Does the probability of transitioning from inhalant use to other drug use remain after controlling for demographic factors and key psychosocial predictors of adolescent drug use?*

1.4 Analytic Approach

The gateway hypothesis suggests that drug use progresses through a series of sequential discrete stages. To address the study research questions, latent transition analysis (LTA) (Lanza, Flaherty, & Collins, 2003), an analytic approach to measuring longitudinal discrete-stage models, was used. LTA is an extension of latent class analysis to repeated measures that allows for the estimation of the prevalence of stages and the incidence of transitions to different stages over time (Lanza et al., 2003).

As a latent variable model, LTA provides a way of statistically modeling transitions between latent states while adjusting for measurement error, thereby producing more accurate model parameters (Collins, 2006). An additional benefit of this latent variable approach is that it accounts for respondents who recant earlier responses, a significant problem in longitudinal data analysis. Observations from individuals who report ever using a drug at one time but report never using that same drug at a later time are treated as measurement error in LTA. This approach is preferable to commonly used tactics such as removing inconsistent reporters from the data set or forcing consistent reports by recoding the responses (Collins, 2006).

To examine the stages and transitions of drug use onset, several latent transition models were estimated for two periods of transition: from 6th to 7th grade and from 7th to 8th grade. These analyses were conducted separately for white males, white females, African American males, and African American females to identify models that best fit the data for each group and to determine whether patterns of drug use differed by race and gender. Drug use stages were defined by the ever or never use of inhalants and the three drugs widely recognized as gateway drugs: alcohol, tobacco (cigarettes), and marijuana. Because of the relatively young sample and the corresponding rarity of illicit drug use, and because this

study focused on the relationship between inhalants and the gateway drugs, the use of other illicit drugs was not included.

Final model parameters were used to assess the prevalence of stage membership at each grade and the probability of transitioning from one stage to another, conditional on baseline stage membership. This approach allowed for the investigation of where, or whether, inhalants fit in gateway drug use sequencing and whether the use of inhalants is associated with an increased probability of progressing to a more advanced drug use stage.

Several sociodemographic and psychosocial variables were included as predictors of the transition probabilities between inhalants and other drugs to assess the strength of the relationship between inhalant use and gateway drug use transitions, while controlling for possible competing factors (i.e., perceived drug availability, perceived peer drug use, sensation seeking and delinquency, academic achievement, and parental [mother's] disapproval of drug use).

1.5 Significance

This dissertation is the first study to evaluate the relationship between inhalant use and the use of gateway drugs in a longitudinal, general population sample of adolescents. Like tobacco, alcohol, and marijuana, inhalants are a widely available class of drugs, and they are used by a significant number of adolescents with an apparent early average age of initiation. Inhalants have neurological and physiologic effects similar to other drugs, and inhalant users report "benefits" of use similar to those reported for other drugs. Although inhalants have been shown to be strongly associated with heroin use and other severe forms of drug abuse, no study to date has explored the prospective relationship between inhalants and the gateway drugs. Using an adolescent sample and an analytic approach uniquely suited

to testing a stage-based model based on the gateway hypothesis, this dissertation provides a preliminary understanding of the role inhalants play in adolescent drug use sequencing.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

2.1 Definition of Inhalants

Inhalants are volatile substances that produce chemical vapors that can be inhaled to induce a psychoactive effect (National Institute on Drug Abuse [NIDA], 2005a). The term "inhalants" is used to describe a broad variety of widely available substances whose main defining characteristic is that they are rarely, if ever, taken by any route other than inhalation (NIDA, 2005a). Because of the large capillary surface area of the lungs and the quick dispersal of blood from the lungs to the brain, inhalation rivals intravenous injection, in terms of intensity, as a means of drug delivery.

Although commonly listed as an illicit drug in reports and articles, inhalants are omnipresent at home, work, and even at school and in most cases can be legally obtained by adolescents. The purchase and possession of inhalants is usually legal, and most of the common household and commercial products abused as inhalants are not regulated under the Controlled Substances Act. Although no federal policy specifically focuses on inhalant abuse, as of 1995, 43 states had passed statutes specifically directed at inhalants (Harwood, 1995). Most of these laws seek to limit access to inhalable products or to change the nature of the inhalable products (e.g., adding irritants to make inhalation uncomfortable). North Carolina has enacted laws making it illegal to abuse certain inhalants, possess certain products for abuse, or sell or transfer such products for abuse and requiring warning labels on inhalable products (Harwood, 1995). However, none of the specific products regulated by the

state are among the most commonly abused. These efforts are not widely enforced, evaluated, or notably successful (Harwood, 1995).

Because the broad definition of inhalants encompasses such a wide range of substances, categorization of inhalants varies, and many surveys treat all forms of inhalants as a single class. NIDA (2005a) classifies inhalants into four general categories: volatile solvents, aerosols, gases, and nitrites.

Volatile solvents, the most commonly abused category of inhalants among adolescents (Substance Abuse and Mental Health Services Administration [SAMHSA], 2004), are found in a large number of widely available, inexpensive products commonly found in the home or in industrial settings (NIDA, 2005a). This class includes liquids that vaporize at room temperature, such as paint thinner and paint remover, gasoline, glues, correction fluid, and felt-tip marker fluid. Glue, shoe polish, and toluene are the most commonly used inhalants among youth aged 12 or 13: in 2002 and 2003, 4.3% of youth reported lifetime use of at least one of these substances. The second most commonly used inhalants are gasoline or lighter fluid, with 3.3% of youth aged 12 or 13 reporting lifetime use (SAMHSA, 2005).

Aerosols are sprays that contain propellants and solvents (NIDA, 2005a). Spray paints, deodorant, and hair sprays are commonly abused sources, with 4.2% of youth aged 12 or 13 reporting lifetime use (SAMHSA, 2005).

Gases are found in household products such as butane lighters, propane tanks, whipped cream dispensers, and refrigerants. This category also includes medical anesthetics, such as ether, chloroform, halothane, and nitrous oxide. Nitrous oxide or “laughing gas” is

commonly abused and is found not only in medical settings but also in whipped cream dispensers and nitrous oxide products used to boost octane levels in racing cars.

Nitrites differ from the other three categories of inhalants in that they act primarily as vasodilators and muscle relaxants. In contrast, other inhalants act directly on the central nervous system and are abused primarily for their ability to alter mood. Nitrites include amyl nitrite, a prescription drug used in the treatment of some heart problems; butyl nitrite, sold in incense and room deodorizers; and isobutyl nitrites (commonly referred to as "poppers") (Newell, Mansell, Spitz, Reuben, & Hersh, 1985). Because of their ability to dilate blood vessels, inhaled nitrites increase the heart rate and produce a sensation of heat and excitement that lasts for several minutes (NIDA, 1998). For this reason, nitrites often are used as sexual enhancers. Another distinguishing factor of nitrites is that nitrite inhalants appear to be more commonly abused by adults than by adolescents, with one study reporting a mean age of 25.6 years for first nitrite use (Lange et al., 1988). Abuse of nitrites has been widely studied in populations of gay and bisexual men, among whom nitrite use appears to be particularly common. One study found that 69% of gay men living in Baltimore and Washington, DC, reported lifetime use of nitrites (Lange et al., 1988). However, nitrites are used by a considerable number of adolescents, particularly adolescents in treatment for substance abuse. One study found that 43% of youth in substance abuse treatment reported a history of nitrite inhalant use (Schwartz & Peary, 1986).

2.2 Physical Effects and Consequences of Inhalant Use

The immediate effects of inhalant use are generally short-lived, lasting 5 to 15 minutes; the products are easy to conceal; and inhalants are not tested in drug screenings, so inhalant use by adolescents is likely not visible to caregivers. Indeed, adolescent inhalant use

usually comes to light only when self-reported by the adolescent or when an adolescent presents with medical problems associated with inhalant use.

Effects from inhaling mirror alcohol inebriation and include mild stimulation, loss of inhibition, and distorted perceptions. Research suggests that inhalants, particularly toluene (found in gasoline, spray paint, and glue), enhance dopamine activity in the brain's pleasure center in much the same way as other drugs of abuse (Riegel et al., 2003).

The wide availability of inhalants may make them an attractive alternative to alcohol, particularly for older children and young adolescents. Because inhalant use produces rapid intoxication, and because the effects generally wear off quickly, inhalant use is easier to conceal than many other drugs of abuse. In an unpublished summary of findings from an inhalant focus group project involving 93 Massachusetts youth, with and without experience with inhalants, respondents indicated several perceived advantages of inhalants over other drugs (Wolfe, 1995). These youth indicated that inhalants cause a desirable "trippy" high, are readily available, can be used without arousing suspicions, are legal and inexpensive, and take effect quickly. The respondents also indicated that they believed they could better control the high they received from inhalants (Wolfe, 1995).

One study assessed the perceived physical and psychological effects of using inhalants among 285 adolescents from juvenile correction facilities in Virginia (McGarvey, Clavet, Mason, & Waite, 1999). When asked to describe the "good things and bad things" experienced while using inhalants, 61% indicated that euphoria (e.g., feeling carefree, happy, amused, high) was an effect of inhalant use and 39% reported hallucinations as an outcome, suggesting possible reasons adolescents choose to use inhalants. Results from this study also suggested that adolescent inhalant users are likely to associate with friends who use inhalants

and that most adolescents obtain and use inhalants at their home or at a friend's home (McGarvey et al., 1999).

Even a single experimentation with inhalants can be dangerous, in some cases causing permanent organ damage or even death. The brain, lungs, kidneys, heart, and liver are all at risk from inhalant use, and death from asphyxiation, suffocation, seizure, coma, choking, and injuries from accidents related to loss of motor control have been reported. "Sudden sniffing death," a syndrome characterized by irregular and rapid heart rhythms resulting in heart failure, has been associated with even a single session of prolonged inhalation (NIDA, 2005a). From 1996 to 1999, an estimated 240 people nationwide died from inhalant abuse, most often as a result of the toxic effects of gas fumes or trauma that was a consequence of the altered state of the user (Bowen, Daniel, & Balster, 1999).

Symptoms associated with withdrawal, including anxiety, sweating, nausea, and restlessness, are experienced by some users. Most inhalants produce a rapid high that resembles alcohol intoxication. If taken in sufficient amounts, inhalants can produce anesthesia, a loss of sensation, and even unconsciousness (NIDA, 2005a). Other possible short-term effects include belligerence, apathy, and impaired judgment and functioning. Inhalant users may demonstrate symptoms such as dizziness, slurred speech, nausea, vomiting, and lethargy shortly after use. Depression, muscle weakness, lack of coordination, and a series of withdrawal symptoms are all associated with long-term or continued inhalant abuse.

Most inhalants are extremely toxic, potentially causing widespread and long-lasting (sometimes irreversible) damage to the brain, central nervous system, and other organs.

Extensive destruction of nerve fibers in the brain similar to that found in diseases such as multiple sclerosis is evident in some chronic inhalant abusers (NIDA, 2005a).

2.3 Sources of Data on Adolescent Inhalant Use

The three primary nationally representative surveys that address adolescent drug use behaviors—the National Survey on Drug Use and Health (NSDUH), the Monitoring the Future (MTF) study, and the Youth Risk Behavior Survey (YRBS)—include information about adolescent inhalant use. These surveys provide national inhalant use prevalence estimates and trend information dating back many years.

NSDUH (formerly the National Household Survey on Drug Abuse [NHSDA]) is a household survey of individuals aged 12 years and older that is sponsored by SAMHSA. From 1979 to 1991, the survey was conducted every 3 years, and since then it has been conducted annually. Data collection occurs throughout the calendar year.

MTF has been conducted annually since 1975 and is funded through grants from NIDA to the University of Michigan Survey Research Center. Eighth, 10th, and 12th grade students from more than 400 public and private secondary schools are surveyed in the spring of each year. Survey administration occurs within the classroom.

YRBS is a national survey of students enrolled in high school (grades 9 through 12), conducted by the Centers for Disease Control and Prevention (CDC) (2006). Surveys are conducted every 2 years and provide data representative of public and private high schools in the United States. Like MTF, YRBS is administered in classrooms in the spring.

Differences in rates across the three studies are commonly reported, although overall trends over time are generally similar (see Banken, 2004; Fendrich & Johnson, 2001; Fowler & Stringfellow, 2001; Harrison, 2001; Brener, Grunbaum, Kann, McManus, & Ross, 2004).

Differences are likely due to a range of factors, although two commonly posited reasons are survey setting (household versus school) and question wording.

For most substances, NSDUH consistently reports the lowest prevalence estimates and YRBS reports the highest, with YRBS and MTF generally being closer to one another than to NSDUH (Fendrich & Johnson, 2001). This discrepancy is at least partially attributed to the fact that NSDUH is conducted in a household setting (Volkow, Fowler, & Wang, 2003), whereas YRBS and MTF are school-based surveys. However, this pattern appears to be less pronounced in the case of inhalants.

Question wording has been posited as a plausible reason for the discrepancy between NSDUH and the other two surveys. In a study on the effects of question wording on prevalence rates, Brener et al. (2004) found that the approach used by NSDUH, which uses a series of questions that explicitly list 10 separate inhalable substances plus an open-ended option for any other products inhaled, produced the largest prevalence estimates for inhalants. YRBS and MTF assess inhalant use specifically as sniffing glue, breathing the contents of aerosol spray cans, or inhaling any paints or spray to get high. The authors conclude that respondents to the YRBS and MTF surveys may not consider all possible inhalants when answering (Brener et al., 2004). Further evidence for the importance of question wording comes from a study of inhalant use in Texas, where 24% of 7th graders indicated that they sometimes "sniffed" or "huffed" one or more of a large list of common inhalants. But when the same youth were later asked a general question about their "inhalant use," about one-half of those 24% indicated that they had never used inhalants (Fredlund, 1992).

NSDUH asks respondents to report their lifetime, past year, and past month use of inhalants, as well as their age at first use of inhalants. NSDUH, which defines inhalants as "liquids, sprays, and gases that people sniff or inhale to get high or to make them feel good," also records the types of inhalants that are commonly used. These include glue, shoe polish, or toluene; gasoline or lighter fluid; spray paint; correction fluid, degreaser, or cleaning fluid; lacquer thinner or other paint solvents; other aerosol sprays; amyl nitrite, "poppers," locker-room odorizers, or "rush" (isobutyl nitrite); lighter gases (Jackowski et al., 2005); nitrous oxide or "whippets"; and halothane, ether, and other anesthetics. The category of inhalants most frequently reported by youth is glue, shoe polish, or toluene; however, among youth who have used an inhalant, more than 50% have used more than one type in their lifetime (SAMHSA, 2003).

Aside from these national surveys, information on adolescent inhalant use comes largely from clinical samples from substance abuse or other treatment centers (e.g., Dinwiddie, Reich, & Cloninger, 1991b; Johnson et al., 1995; Sakai, Mikulich-Gilbertson, & Crowley, 2006) or special populations such as antisocial, delinquent, and/or incarcerated youth (e.g., Howard & Jenson, 1999; Mackesy-Amiti & Fendrich, 1999; McGarvey, Canterbury, & Waite, 1996) and minorities (Mosher, Rotolo, Phillips, Krupski, & Stark, 2004), in particular Native American adolescents (e.g., Beauvais, Wayman, Thurman, Plested, & Helm, 2002; Howard, Walker, Walker, Cottler, & Compton, 1999; Novins & Baron, 2004; Novins, Beals, & Mitchell, 2001).

2.4 Epidemiology of Inhalant Use

2.4.1 Age of Initiation

The mean age of first use of inhalants varies between surveys, but it is generally between 11 and 13 years (Wu, Pilowsky, & Schlenger, 2005; Costello, Erkanli, Federman, & Angold, 1999). Findings from NSDUH suggest that, for very young adolescents, inhalants are among the most commonly tried drugs. Data from the 2003 NSDUH indicate that a higher percentage of youth aged 12 or 13 had used inhalants than marijuana in the past year (SAMHSA, 2004). Likewise, data from the MTF survey show that, in 2004, 17.3% of 8th graders had used inhalants in their lifetimes, compared with 16.3% reporting use of marijuana (Johnston et al., 2005). In part because inhalant use appears to peak during early adolescence, this study focuses on the transitions from 6th grade to 7th grade and from 7th grade to 8th grade.

2.4.2 Current Prevalence of Inhalant Use

Inhalant use among adolescents is prevalent, with inhalants being the most widely used illicit drug among young (< 14 years old) adolescents (SAMHSA, 2008; Johnston et al., 2005, 2007; Wu et al., 2004) and second to marijuana among 8th and 10th graders in the United States (Johnston et al., 2001). Among past year illicit drug users aged 12 or 13, 45.5% had used inhalants, whereas 28.4% had used marijuana (SAMHSA, 2008). More than 1 million Americans become new inhalant users annually (SAMHSA, 2003), and inhalants appear to be among the only drugs showing evidence of increasing use among adolescents in the United States (Johnston et al., 2005). More than 2 million U.S. teenagers have used inhalants to get high at some time in their lives (Wu et al., 2004).

As previously noted, prevalence estimates from the three primary national surveys on adolescent drug use differ. In 2005, the MTF study reported estimated prevalence of lifetime

(ever) use of inhalants for 8th, 10th, and 12th graders as 17.1%, 13.1%, and 11.4%, respectively (Johnston, O'Malley, Bachman, & Schulenberg, 2006a). The 2005 prevalence estimates from NSDUH for the same grades were 11.9%, 11.4%, and 11.3%, respectively (SAMHSA, 2006). Prevalence estimates from the 2005 YRBS were 14.1% of 9th graders, 13.2% of 10th graders, 11.4% of 11th graders, and 10.1% of 12th graders (CDC, 2006).

Consistent with all three data sources is the seemingly nonsensical finding that lifetime use prevalence estimates for inhalants decline as adolescents age, although the decline is much sharper for the two school-based surveys (YRBS and MTF). Conceptually, the rate of lifetime use should increase or stay stable over time, as is seen for trends of other drugs. One possible explanation is that inhalant use is disproportionately common among the school drop-out population and that NHSDUH, which potentially includes school dropouts, better captures that population. It also has been noted that older respondents may be less prone to report inhalant use because inhalants are seen as an "immature" class of drugs and are less socially acceptable (Kurtzman, Otsuka, & Wahl, 2001; Johnston, O'Malley, Bachman, & Schulenberg, 2006a).

Although national estimates suggest that inhalants are one of the most commonly tried substances, recent use measures (e.g., past month) suggest that consistent or chronic use of inhalants is rare. In 2005, only 1.4% of 8th graders, 1.2% of 10th graders, and 0.3% of 12th graders in NSDUH reported past month use of inhalants (SAMHSA, 2006). The rates for the same grades were higher for MTF (4.2%, 2.2%, and 2.0%, respectively), but they were still low relative to alcohol, cigarettes, and marijuana (Johnston et al., 2006a). YRBS does not include a past month measure of inhalant use.

2.4.3 Trends in Inhalant Use

Adolescent inhalant use peaked in 1995. At that time, nearly 22% of 8th graders sampled in the MTF survey reported ever having used an inhalant. In response, the Partnership for a Drug-Free America conducted a well-funded, widely distributed national media campaign highlighting the health consequences of inhalant abuse. Although not formally linked solely to the media campaign, abuse of inhalants decreased substantially among 8th, 10th, and 12th graders after 1995, according to the MTF survey (NIDA, 2005b). Further evidence of a potential effect of the campaign is reflected in a decrease in the number of 8th and 10th graders who believe that inhalant abuse is dangerous in the years following the end of the campaign (NIDA, 2005b).

According to the 2004 MTF survey (Johnston et al., 2005), the abuse of most drugs among adolescents in the United States declined significantly in the past 3 years. These declines were not realized for inhalants, however. Past-year inhalant use increased from 2003 to 2004 for all students surveyed, and lifetime inhalant abuse among 8th graders increased from 15.8% in 2003 to 17.3% in 2004, the second year in a row an increase was reported (Johnston et al., 2005).

2.5 Prevalence of Inhalant Use in North Carolina

YRBS provides state-level estimates for a wide range of licit and illicit drugs, including estimates of lifetime inhalant use. In 2003, 15.4% of North Carolina 9th through 12th graders reported lifetime inhalant use, a percentage significantly higher than the national average from this survey of 12.1%. By 2005, the prevalence of lifetime inhalant use had dropped to 11.9%, although the differences between years and between North Carolina and the United States were not statistically significant (CDC, 2006).

2.6 Demographic Correlates of Inhalant Use

2.6.1 Gender

In general, gender does not appear to be strongly associated with inhalant use, and prevalence appears to be similar for males and females, although in some studies females have higher prevalence rates at earlier grades. Data from the 2005 NSDUH suggest that an equal number of male and female respondents ages 12 to 17 have ever used inhalants (10.5%) and have used inhalants in the past month (1.2%) (SAMHSA, 2006). However, whereas past-year inhalant use among males remained stable between 2002 and 2005, it increased among females from 4.1% in 2002 to 4.9% in 2005 (SAMHSA, 2007). Results from the 2005 YRBS showed a significantly higher prevalence rate for 9th grade females (17.3%) than males (11.0%), but the difference was not significant at 12th grade (CDC, 2006). Data from the 2005 MTF suggest that the prevalence of inhalant use is higher for females than for males in the 8th grade (19.1% versus 14.9%) and 10th grade (14.5% versus 11.6%) but not in the 12th grade (9.3% versus 13.7%).

Using combined data from the 2000 and 2001 NHSDA, Wu, Pilowsky, and Schlenger (2004) found no difference in inhalant abuse among 12- to 17-year-olds based on gender, an almost unique finding among drugs of abuse—in most cases, adolescent males are more likely than females to use illegal drugs. However, the percentage of 18- to 25-year-old males who abused inhalants within the past month was more than twice that of females in the same age group, suggesting that long-term use of inhalants is more common among males.

It has been posited that adolescent males' "*overall higher likelihood of involvement with drugs may relate to their more frequent exposure to situations in which these drugs are available. Inhalants may be an exception because boys and girls have the same level of access to them"* (NIDA, 2005b, p. 7). The finding of gender similarity in inhalant use

highlights the potential importance of availability and access as predictors of adolescent inhalant use. More generally, Van Etten and Anthony (2001) found that across age, race, region, and urban status subgroups, after controlling for opportunities to use drugs, women were as likely as men to initiate drug use.

No identified studies have determined whether drug use sequencing that includes inhalants differs between males and females. For example, females have similar rates of inhalant use but generally lower rates of other substance use than males; therefore, it is feasible that inhalants may play a more important "gateway" role for females.

2.6.2 Race/Ethnicity

As is the case with most drugs of abuse, African American adolescents tend to have substantially lower inhalant use rates than whites and Hispanics. Data from the 2005 NSDUH and YRBS suggest that whites and Hispanics have similar lifetime prevalence rates, whereas African Americans' rates are significantly lower. Among 9th through 12th graders in the 2005 YRBS, 13.4% of whites, 13.0% of Hispanics, and only 6.8% of African Americans reported lifetime ever use of inhalants (CDC, 2006). Similar findings are reported for the 2005 NSDUH, although the discrepancy is not as pronounced: 10.8% of whites, 10.2% of Hispanics, and 9.4% of African Americans aged 12 to 17 reported lifetime use of inhalants (SAMHSA, 2006). While it is well established that African American and white adolescents differ in terms of prevalence of drug use, it remains untested whether there are fundamental differences in drug use sequencing between the two groups, particularly when inhalants are considered. Given the higher prevalence rates for inhalant use among white adolescents, it is hypothesized that inhalant use will play a more prominent role in drug use sequencing for white adolescents.

2.7 Characteristics of Adolescent Inhalant Users

Beauvais and Oetting (1987) have proposed that inhalant users can be classified into three general categories: inhalant-dependent adults, polydrug users, and young inhalant users. *Inhalant-dependent adults* tend to use inhalants predominantly and have done so for an extended period of time. They generally have very poor prognoses, including high rates of heavy use of other drugs and poor physical and mental health. *Polydrug users* may use a wide array of substances, and inhalants are often used when their drugs of choice are not available. Polydrug users can be any age, although they are typically between the ages of 15 and 18. Polydrug users represent a wide range of characteristics reflecting in part their primary drug of choice, and they tend to have profiles similar to others who abuse their primary drug of choice. They are likely to have significant antisocial propensities. *Young inhalant users* represent the relatively widespread experimental use by adolescents who tend to be very young (typically between the ages of 12 and 13). They are likely to be experimenting with other drugs, particularly drugs commonly referred to as gateway drugs—alcohol, cigarettes, and marijuana—although the sequencing and possible prospective relationships between these drugs has not been investigated in younger adolescents, the period most likely to be associated with experimenting and initiating the use of gateway drugs.

In general, inhalant users are likely to report family problems and impaired family functioning (McGarvey et al., 1996, 1999; Morita et al., 1996; Tapia-Conyer, Cravioto, Delarosa, & Velez, 1995), while parental monitoring and knowledge of the health risks of inhalants appear to be strong protective factors (Ramirez et al., 2004). Inhalants are often the first substance used by youth incarcerated in juvenile detention facilities (Young, Longstaffe, & Tenenbein, 1999). Inhalant use has been found to be strongly associated with antisocial

personality disorder (Compton et al., 1994; Dinwiddie, Reich, & Cloninger, 1990) and depression (Kelder et al., 2001; Sakai et al., 2004), and inhalant users are more likely than nonusers to have serious problems in school (Oetting & Webb, 1997). Academic performance appears to be an especially strong correlate of inhalant use (Mackesy-Amiti & Fendrich, 2000).

The association between inhalant use and deviant behavior is particularly noteworthy. Although deviant behavior has generally been associated with any drug use, this association is stronger for inhalant use than for any other drug (Mackesy-Amiti & Fendrich, 1999; Mosher et al., 2004), leading some authors to suggest that inhalant use is categorically different from other drug use and that inhalant use may have more in common with general delinquent behaviors than with other drug use (Mackesy-Amiti & Fendrich, 1999).

Youth attending alternative high schools appear to be much more likely to use inhalants. Lifetime prevalence estimates from national samples suggest that about 17% of 8th through 12th grade students have used inhalants (Johnston et al., 2005). But the estimates for adolescents attending alternative high schools are much higher. Among students completing the national Alternative High School Youth Risk Behavior Survey (ALT-YRBS) in 1998, 27% reported lifetime use of inhalants (Grunbaum et al., 2000). Results from a later study of alternative high school students from Texas were nearly identical: prevalence of lifetime inhalant use was 28% (Fleschler, Tortolero, Batumler, Vernon, & Weller, 2002). Among this population, weapon carrying, suicidal ideation, alcohol/tobacco use, marijuana use, and cocaine use were all strongly associated with inhalant use. In a multivariate model including these items and demographic characteristics, the odds of using alcohol or tobacco were 7.7 times greater for lifetime inhalant users than for abstainers. The odds of using marijuana

(10.3 times greater) and cocaine (17.2 times greater) were even more striking (Fleschler et al., 2002) and seem to suggest that inhalant users, even among a high-risk population, are at particularly high risk for serious drug involvement.

Friends' use of drugs has consistently been shown to be one of the strongest predictors of drug use. Beuvais, Wayman et al. (2002) found this to be the case with inhalants as well, finding that peer sanctions against use, peer use, and peer encouragement to use were all significant predictors of recent use (i.e., use in the past 30 days) and lifetime use, the relationship being much stronger for use in the past 30 days and for non-Latino white adolescents (relative to American Indian and Mexican American adolescents). The strongest peer predictor of inhalant use was the degree to which friends are perceived to use them (assessed by a question asking how many of their friends sniff glue, gas, or other inhalants). This predictor was again most strongly associated with past 30 day use and was strongest for non-Latino white students and weakest for American Indian students. A white student reporting friends who used inhalants was 17.87 times more likely to be using inhalants than a student who did not have friends who use (Beauvais, Wayman, et al., 2002). The authors concluded that the particularly strong effects of peers on recent (past 30 days) use may reflect "peer clustering," where adolescents who continue to use inhalants may select a sphere of friends who are also using (Beauvais, Wayman, et al., 2002; Oetting & Beauvais, 1986). Another well established possible explanation for the strong relationship between perceived peer use and adolescent use is projection, where adolescents believe that their friends and peers do what they do themselves. This phenomenon tends to inflate the relationship between perceived peer use and adolescent substance use (Prinstein & Wang, 2005; Norton,

Lindrooth, & Ennett, 2003; Krueger & Stanke, 2001; Kandel, 1996; Bauman & Ennett, 1996; Marks, Graham, & Hansen, 1992).

One epidemiologic study (Mosher et al., 2004) has demonstrated how unique characteristics define inhalant users, when compared with users of other drugs. Although Mosher et al. found that some of the more consistent characteristics of youth who abuse drugs (e.g., low parental attachment, drug use by parents, low school achievement) were also common among young inhalant users, one of the most widely reported predictors of substance use—peer or friend use of the substance (Beauvais, Wayman, et al., 2002)—was not a significant predictor of inhalant use.

However, the scale measure of "friend's drug use" used in this study did not include an item for friend's use of inhalants. Although general drug use among peers may not influence inhalant use, peer inhalant use very well may (Beauvais, Wayman, et al., 2002). It seems likely that youth who are experimenting with inhalants are associating with other youth who are as well (Oetting & Donnermeyer, 1998). It also should be noted that this study was focused on minority adolescents. It is reasonable to expect that drug-using cultures and patterns of use may differ among different racial/ethnic and cultural groups.

According to the latest MTF survey (2005), only 38.7% of 8th graders believe it is dangerous to try inhalants once or twice, a number that has declined for the past 3 years. Notably, these results mirror the rising rates of inhalant use among this population during the same period. Adolescent perceptions of the harm involved in using drugs have been shown to have a strong, inverse relationship with the use of a number of drugs (Johnston et al., 1998), although this relationship has not been demonstrated directly for inhalants. In one of the only studies to assess the relationship between perceived harm from using inhalants and inhalant

use, Beauvais, Jumper-Thurman, Plested, and Helm (2002) found that perceived harm from occasional use of inhalants was a significant predictor of inhalant use, although this factor was weaker than other predictors included in analyses, primarily dealing with peer influence.

2.8 Theoretical Perspectives on Drug Use Sequencing

2.8.1 The Gateway Hypothesis

In 1970, Dr. Robert DuPont, drug czar under President Richard Nixon, used the term "gateway drug" to define drugs that when used appear to lead to the use of more progressive and dangerous substances (Kandel, 2002). Often called "Stage Theory," the gateway hypothesis has played a major role in understanding how adolescents transition through a surprisingly consistent sequence of drug use (Kandel & Yamaguchi, 1985, 1999, 2002; Kandel et al., 1992; Kandel, 1975, 1988; Kandel & Logan, 1984; Kandel & Faust, 1975).

The basic premise of the gateway hypothesis is that the use of various classes of drugs follows definite pathways, suggesting that an individual who participates in one drug behavior is at risk of progressing to another (Wu et al., 2004). Kandel and Jessor (2002) identified three primary propositions of the gateway hypothesis. The first proposition is that there is a developmental sequence of involvement with different classes of drugs, such that initiation into drug use begins with legal and widely available drugs (tobacco and alcohol). Marijuana use is seen as a bridge between these legal substances and the use of other illicit drugs. Support for this proposition is strong, with numerous studies replicating the general sequence during the past 30 years (e.g., Kandel & Yamaguchi, 1985, 1999, 2002; Kandel et al., 1992; Kandel, 1975, 1988; Kandel & Logan, 1984; Kandel & Faust, 1975; Graham et al., 1991; Collins et al., 1994; Collins, Graham, Rousculp, & Hansen, 1997; Hyatt & Collins, 2000).

The second proposition is that the use of a drug earlier in the sequence is associated with an increased risk or likelihood of use of a drug later in the sequence; as with the first proposition, there is strong empirical evidence to support this second proposition (e.g., Guo et al., 2002; Hawkins, Hill, Guo, & Battin-Pearson, 2002; Kandel, 1975, 2003; Kandel & Faust, 1975; Kandel et al., 1992; Ellickson, Hays, & Bell, 1992).

The third proposition is the most controversial and, according to some researchers, the most abused proposition. It states that the use of a drug earlier in the sequence *causes* the use of a drug later in the sequence. This proposition is often cited among intervention planners and during policy debates as a rationale for focusing efforts and resources on the prevention of gateway substances. After years of study and review, Kandel and Jessor (2002) concluded that support for the third proposition is lacking, largely due to the inherent difficulties in establishing causality and that "interpretations of the gateway hypothesis should be restricted to the propositions about sequencing and association…The causation proposition is without evidential support at this time" (p. 372).

Yamaguchi and Kandel (1984b) caution that the notion of a gateway sequence of drug use does not imply that these stages are universal or uniformly necessary, and they point out that not all individuals progress through the gateway sequence. Most stop at occasional alcohol and/or tobacco use: "The existence of stages of progression…does not necessarily imply causal linkages among different drugs since the observed sequences could simply reflect the association of each class of drugs with different ages of initiation and/or individual attributes rather than the specific effect of the use of one drug class on the use of another" (Yamaguchi & Kandel, 1984b, p. 671). Despite this caveat, it is clear that the gateway

hypothesis has been interpreted and used as evidence that the use of gateway drugs causes the use of illicit drugs.

The gateway hypothesis of substance use posits a progressive and hierarchical sequence of drug use stages. According to the gateway hypothesis, a substance user begins his or her use by first using alcohol or tobacco, substances that are legal for adults, prevalently used, widely available, and heavily marketed. The next substance in the sequence is marijuana, followed by other illicit drugs. A central tenet of the gateway hypothesis is that the use of a drug in an early stage is a necessary but not sufficient precursor to the use of a drug in a later stage. Not all users progress through the stages; many will end their use at an early stage, and the use of a drug early in the sequence does not alone predict advancement to a later stage. But users of drugs such as heroin, cocaine, and crack will almost invariably have used marijuana, having first used alcohol and/or tobacco.

This sequencing has been extremely consistent in adolescent studies using representative or large school- and community-based samples (Kandel & Yamaguchi, 2002; Kandel et al., 1992; Kandel, 1975; Kandel & Faust, 1975; Golub & Johnson, 2001; Federman, Costello, Angold, Farmer, & Erkanli, 1997). In a seminal study spanning 20 years, early use of alcohol and cigarettes was the strongest predictor of progression to marijuana and other illicit drugs after controlling for a number of theoretical and empirical predictors of substance use (Kandel et al., 1992). The vast majority of this literature, however, has been based on retrospective data. Few studies have used prospective approaches to estimate substance use progression probabilities (Guo et al., 2002; Hawkins, Hill, Guo, & Battin-Pearson, 2002; Kandel, 1975, 2003; Kandel & Faust, 1975; Kandel et al., 1992; Ellickson, Hays, & Bell, 1992).

No study to date has prospectively assessed whether or where inhalants fall within the gateway sequence. In many ways, inhalants resemble alcohol and tobacco; they are even more widely and readily available than either alcohol or tobacco and are legal to purchase and own in most states. Because inhalants are strongly associated with other drug use and are typically tried at an early age, it has been posited that inhalants may be an unidentified gateway drug, although some have argued that inhalants are better conceptualized as being a marker for later problematic use.

Although the gateway hypothesis has been prominent in the substance abuse research literature, particularly among substance abuse policy advocates and intervention planners, there continues to be significant debate regarding the utility of the hypothesis in explaining drug use progression. Competing literature suggests that common, underlying factors associated with the use of various drugs provides a better explanation of drug use progressions.

Because many drug use prevention activities and policies are founded and designed on the belief that the prevention of gateway drug use may lead to the prevention of illicit drug use, it has been possible to test the gateway hypothesis via natural experiments. Studies that assess the impact of variations in exposure to policies aimed at reducing supply and increasing prices of gateway drugs (via tax increases, restrictive use laws, increased law enforcement) or interventions aimed at reducing demand for gateway drugs (for instance, via health promotion efforts such as anti-tobacco, -alcohol, or -marijuana media campaigns) may provide indirect evidence for or against the gateway hypothesis.

If a gateway drug is causally linked to subsequent illicit drug use, policies and interventions that limit the use of the gateway drug will eventually affect demand for the

illicit drugs. Conversely, if a common factor model rather than the gateway model is more appropriate, policies and interventions targeting gateway drugs are not likely to affect the use of other drugs and may actually lead to substitution, whereby individuals switch to a substitute drug when supply of their drug of choice is diminished.

Findings that policies or interventions aimed at tobacco, alcohol, or marijuana use are influencing rates of drug use later in the gateway sequence would support the gateway hypothesis. For instance, Pacula (1998) demonstrated that higher cigarette prices associated with changes in cigarette excise tax policies have a negative, significant effect on current decisions to use marijuana and alcohol and that increases in the beer tax or the legal drinking age decrease the demand for marijuana by at least as much as they decrease alcohol consumption. Farrelly, Bray, Zarkin, and Wendling (2001) found evidence that higher cigarette taxes are linked with decreased intensity of marijuana use and may have a modest effect on the probability of use, especially among males. They concluded that a 10% increase in cigarette prices would lead to a 5.4% decrease in total marijuana use. Beenstock and Rahav (2002) also found support for the gateway effect of cigarette consumption on marijuana use in Israel. Using a natural experiment, they randomly varied cigarette smoking rates by birth cohort and cigarette prices and were able to demonstrate that people who grew up when cigarettes were relatively cheap were more likely to smoke and to start smoking younger. As a causal consequence, they were more likely to initiate marijuana use and initiate earlier. Their findings did not support a gateway effect for marijuana on illicit drug use, however.

In contrast, other notable studies have found that certain drugs operate as substitutes rather than complements, as evidenced by increases in the use of one drug as a result of

changes in access to another. For instance, Picone, Sloan, and Trogdon (2004) found in an older adult population that while smoking bans (in public places) led to a decrease in alcohol consumption among females, higher cigarette prices (associated with the tobacco settlement of 1998) led to an increase in alcohol consumption for males and females. They explained this apparent disparity in findings by suggesting that smoking bans in bars might keep social drinkers away and subsequently reduce their opportunities to consume alcohol. Describing a potential unintended consequence of alcohol policy, DiNardo and Lemieux (2001) found that while increasing the legal minimum drinking age slightly reduced the prevalence of alcohol consumption, the same policy appeared to slightly increase the prevalence of marijuana consumption. They concluded that alcohol and marijuana may serve very similar short-term purposes to the user, making them potential substitutes for each other.

Literature on the effects on illicit drug use of health promotion interventions aimed at gateway drugs also provides some evidence supporting the gateway hypothesis. Graham, Marks, and Hansen (1991) examined 1-year prevention data and demonstrated that students exposed to a normative education campaign were less likely to transition from a lower-ranked class of drug use to a higher-ranked class. Spoth, Reyes, Redmond, and Shin (1999) found that students receiving a family-focused intervention were less likely to transition from nonuse to drug use compared with students in a control group. Scheier, Botvin, and Griffin (2001) examined drug progression in a cohort of middle school students participating in a school-based drug prevention trial over a 4-year period. They found that program effects disrupted drug progression by decreasing alcohol and cigarette use over 1 year and reducing cigarette use over a 2-year period.

Botvin, Scheier, and Griffin (2002) summarized 20 years of research on the effects of Life Skills Training, a multicomponent prevention approach, concluding that preventing the use of substances hypothesized to occur at the very beginning of the developmental progression (tobacco and alcohol use) not only deters the use of those substances but also deters the use of marijuana and of at least some illicit drugs. Similarly, Pentz and Li (2002) found that early program effects of a multicommunity-based drug prevention trial on gateway drug use mediated later effects on amphetamine use.

Biglan and Smolkowski (2002) evaluated the effects of a smoking prevention intervention that targeted influences posited to affect only smoking. They posited that this would provide a relatively clean test of the gateway hypothesis, as tests of more general prevention approaches include interventions that are likely to have direct effects on illicit drugs. They found that in intervention communities the increase in alcohol use was approximately zero while there was a significant increase in alcohol use in the control communities across 5 years of assessment. Likewise, they found that while marijuana use increased in control communities, the rate of increase was significantly slowed in the intervention communities. These findings suggest that the intervention aimed specifically at preventing cigarette smoking may have had an impact on alcohol and marijuana use as well.

Collectively, these results suggest that a relatively stable progression of drug use best characterizes the experience of most drug users. Individuals who progress to the use of illicit drugs have almost invariably first used alcohol and/or tobacco and marijuana. Although it is unclear whether the use of a gateway drug causes later illicit drug use, the temporality and association between gateway drug use and later illicit drug use is strong and robust. Limited

evidence from intervention and policy studies suggests that efforts to reduce the initiation and use of gateway drugs can have an impact on the use of illicit drugs.

2.8.2 Common Liability Models of Drug Use

Critics of the gateway hypothesis, often citing general theories of problem behavior including Problem Behavior Theory (Jessor & Jessor, 1977), the general theory of crime proposed by Gottfredson and Hirschi (1990), and other social psychological delinquency theories (Rebellon & Van Gundy, 2006), have adopted a "common cause" view of drug use. A common cause argument posits that drug use is simply a manifestation of an underlying individual propensity for deviance coupled with opportunities to use certain substances. According to this critique, the gateway sequence simply reflects social norms, availability, and opportunity. Gateway drugs (tobacco and alcohol in particular) are used first because they are the most widely available and most accepted by society. Particular substances selected by an individual may reflect differences in opportunity for use. Supporting the potential importance of availability of drugs for explaining the progression to polydrug use, Collins et al. (1998) found that drug offers and drug availability were significantly predictive of simultaneous polydrug use.

Common liability models suggest that early substance use is just one marker of a broader underlying construct of developmental difficulties. Morral, McCaffrey, and Paddock (2002) used a simulation study to demonstrate that the presumptions of the gateway hypothesis as it relates to the progression from marijuana use to illicit drug use can be explained completely by the order in which opportunities to use marijuana and illicit drugs occur and by assuming a general propensity to use drugs.

Findings from the simulation study did not disprove the existence of a marijuana gateway effect, but they did demonstrate that the primary evidence supporting gateway

effects was equally consistent with an alternative model of adolescent drug use initiation in that the use of marijuana has no direct effect on later illicit drug use. Accounting for a general propensity to use drugs completely explained the association between marijuana use and illicit drug use. The authors concluded that marijuana policies would have little effect on illicit drug use rates unless they affected the individual's underlying propensity to use drugs (e.g., by increasing general self-efficacy or academic achievement) or reduced access to illicit drugs. Support for Morral et al.'s findings and for the "common factor" model has been presented in epidemiological studies (Agrawal, Neale, Prescott, & Kendler, 2004a; Tarter et al., 2006).

Of note are several studies suggesting that the gateway sequence, robust when applied to general population samples, is less consistent when applied to certain specific populations. Variations in the typical gateway sequence have been noted for different generations (Fisher, Mackinnon, Anglin, & Thompson, 1987) and ethnic/cultural groups (Guerra, Romano, Samuels, & Kass, 2000; Novins et al., 2001). Significant differences in drug use sequencing have been reported for clinical samples of drug- or alcohol-dependent individuals (Golub & Johnson, 1994; Martin et al., 1996). In an analysis of data from the Arrestee Drug Abuse Monitoring program, Golub and Johnson (2002) found that drug use progressions varied significantly from the traditional gateway sequence for a significant percentage of daily illicit drug using criminal offenders. This finding led the authors to posit that, although the use of gateway drugs may be an important risk factor or perhaps risk marker for future illicit drug use among high-risk populations, the use of gateway drugs may not be a central cause of illicit drug use (Golub & Johnson, 2002b).

Polydrug users may also represent a unique population characterized by different drug use sequencing. Although prospective data on this question are lacking, Novins et al. (2001) found that 75% of rural American Indian adolescents who had retrospectively reported ever using three or more substances reported a sequence of first use that was inconsistent with the gateway hypothesis, leading the authors to conclude that the traditional formulation of the gateway hypothesis may not be applicable to polydrug users. Youth who initiated their substance use before age 13 were also less likely to report a sequence of use that was consistent with the gateway hypothesis. In a later longitudinal study using the same sample, Novins and Baron (2004) found that, compared with any other group, individuals who initiated their substance use with marijuana and/or inhalants were at far greater risk for progressing to the use of an illicit drug, and multiple classes of drugs, "later" in the gateway sequence.

Although these studies of rural American Indian adolescents did not support the specific gateway hypothesis, they did find that, in general, most youth used alcohol, marijuana, and/or inhalants before using other illicit drugs, a finding that may reflect the higher rates of inhalant use among both polydrug users and American Indians. Unfortunately, because the survey instrument did not differentiate tobacco misuse from the ceremonial use of tobacco, the authors were unable to include tobacco use in their analyses. The results from these studies are clearly not generalizable to a general population sample and may reflect the distinctly different drug use patterns of this population.

It has been suggested that inhalant use may be more closely related to delinquency than to the use of other drugs (Sakai et al., 2004) and that inhalants may serve as an early marker for particularly problematic behavior (Howard & Jenson, 1999; Borges, Walters, &

Kessler, 2000; Kelder et al., 2001; Mackesy-Amiti & Fendrich, 2000; Sakai et al., 2004; Wu et al., 2004). This finding would seem to support a basic premise of "common cause" models—that rather than reflecting a unique set of predictors, the use of drugs (along with other problematic behaviors) is a result of an underlying propensity for problem behavior. An implication of this premise is that interventions should be aimed at a wide range of risk behaviors rather than at a single substance or class of substances.

Several common liability factors have been consistently cited. Although operationalized in various ways, it has been argued that a general propensity or liability to engage in problem or delinquent behavior, and not the use of a gateway drug, predicts transitions to drug use (Jessor, 1991; Donovan, Jessor, & Costa, 1988; Jessor & Jessor, 1977; Rebellon & Van Gundy, 2006; Jones & Quisenberry, 2004; Benda, 2002; Vazsonyi, Pickering, Junger, & Hessing, 2001; Pratt & Cullen, 2000; Kirisci, Vanyukov, & Tarter, 2005; Vanyukov et al., 2003). Factors such as an individual's risk-taking or sensation-seeking propensity (Hittner & Swickert, 2006; Yanovitzky, 2005; Robbins & Bryan, 2004; Martin et al., 2004; Slater, 2003; Hansen & Breivik, 2001; Donohew et al., 1999) or lack of self-control (Smith, 2004; De Li, 2004; De Wit & Richards, 2004; Wills & Dishion, 2004) are thought to increase the likelihood of engaging in problem behaviors, including drug use.

Problem Behavior Theory (Jessor & Jessor, 1977; Donovan & Jessor, 1985; Jessor, 1987, 1991; Donovan et al., 1988; Costa, Jessor, & Donovan, 1989; Donovan, Jessor, & Costa, 1991) often serves as the foundation of common cause arguments against the gateway hypothesis. In Problem Behavior Theory, variables related to social control (e.g., parental disapproval and monitoring of drug use, neighborhood access to drugs) and social modeling (e.g., peer drug use), an individual's personality and psychosocial characteristics (e.g.,

sensation seeking), and an individual's behavior system (e.g., high involvement in problem behaviors and low involvement in conventional behaviors) are thought to interact to determine an adolescent's overall level of problem behavior propensity.

In this framework, an adolescent's involvement in any one problem behavior increases the risk for involvement in other problem behaviors. But whereas in the gateway hypothesis the use of one drug is thought to directly increase the risk of using other drugs, the relationship is viewed as indirect in Problem Behavior Theory. Specifically, it is the opportunities associated with engaging in problem behaviors (e.g., affiliating and interacting with deviant peers, having access to different substances) and the psychological "meaning" of the behaviors (e.g., rebelling against social conventions, seeking independence from parents) that explain the high covariance between problem behaviors.

2.8.3 Reconciling the Gateway Hypothesis and Common Liability Models

In truth, these challenges to the gateway hypothesis are not necessarily incommensurate with it. Although a few studies have illustrated patterns of drug use that are not entirely consistent with the most commonly described gateway sequences, even opponents of the gateway hypothesis note that the general sequence—transitions from widely available and socially acceptable substances to illicit drugs—is remarkably consistent across studies and populations. Whereas the gateway hypothesis suggests that the use of a particular drug directly increases the probability of using a drug later in the sequence, a common liability argument suggests that the ordering of drugs used simply reflects the social norms and opportunities to use associated with each drug.

According to the gateway hypothesis, the use of a drug early in the sequence (particularly alcohol and marijuana) is a necessary but not sufficient precedent for the use of illicit drugs. Proponents of a common liability model argue that the sequencing of drugs is

merely an artifact; alcohol and tobacco are the first drugs used simply because they are the most widely available, and individuals who progress to illicit drug use do so for reasons related to an underlying propensity. Under both models, however, the stages of drug use remain similar and are robust across a wide range of samples. In addition, both viewpoints highlight the importance of drug availability and opportunities to use as at least partially explaining the gateway role seen for alcohol, tobacco, and marijuana. The key distinction is that, according to the gateway hypothesis, the use of a gateway drug increases the likelihood of using another drug, perhaps through direct pharmacologic or neurological effects associated with use of the gateway drug. Put simply, according to the gateway hypothesis, the use of a gateway drug produces direct effects that lead to an increased probability of later drug use.

This dissertation does not seek to reconcile or directly contrast the gateway hypothesis with the common liability theories. To do so would likely require animal-based molecular, biological, and pharmacological experiments to explore questions of causation (Kandel, Yamaguchi, & Klein, 2006). But by exploring the role that inhalants—perhaps the most widely available class of drugs of abuse—play in drug sequencing, this dissertation tests a key assumption underlying both the gateway hypothesis and the common cause theories: that drug availability (in part) predicts how early in the drug use sequence a drug is used. Furthermore, this dissertation separately tests the association between inhalant use and other drug use stages and transitions while controlling for demographic characteristics and several key components cited by proponents of a common cause model, including perceived drug availability, perceived peer drug use, sensation seeking and delinquency, academic achievement, and parental (mother's) disapproval of drug use.

According to the gateway hypothesis, a gateway drug should have a direct and significant impact on probabilities of transitioning to later drug use. Conversely, a common liability model suggests that, when taking into account underlying individual characteristics and drug use opportunities associated in general with an increased risk of drug use, the prospective relationship between a gateway drug and later drug use transitions will diminish. By first examining whether inhalants operate as a full or partial gateway to the established gateway drug marijuana and then testing whether the relationship between inhalant use and other drug use remains after adjusting for theorized common liabilities, this dissertation examines the potentially predictive role inhalants play in gateway drug use pathways.

2.9 Preliminary Evidence of a Gateway Relationship between Inhalant Use and Other Drug Use

2.9.1 Similarities between Inhalants and Other Drugs

As with other drugs of abuse, people who use inhalants can build up tolerance (Ron, 1986), develop cravings associated with dependence (Anthony et al., 1994; Howard et al., 2001), and experience significant withdrawal symptoms (Brouette & Anton, 2001). The signs of addiction suggest that inhalants operate similarly to other drugs of abuse. Inhalants have been demonstrated, primarily in animal studies, to produce effects similar to ethanol (alcohol) and other central nervous system depressants (Knisely, Rees, & Balster, 1990; Rees, Knisely, Breen, & Balster, 1987; Rees, Knisely, Balster, Jordan, & Breen, 1987; Bowen & Balster, 1997a, b; Wiley, Bowen, & Balster, 2001; Bowen & Balster, 1998a, b; Balster, Bowen, Evans, & Tokarz, 1997; Bowen, Wiley, & Balster, 1996; Bowen, Wiley, Jones, & Balster, 1999; Balster, 1998). It appears plausible, albeit untested, that early use of inhalants may condition an individual's brain to crave drug-associated effects. A similar hypothesis has been forwarded to explain the apparent gateway effects of tobacco, alcohol,

and marijuana (Hall & Lynskey, 2005; Kelley & Rowan, 2004; Solinas, Panlilio, & Goldberg, 2004; Lindsay & Rainey, 1997).

Comparing the clinical features of inhalants, methamphetamine, alcohol, and nicotine dependence, Miyata et al. (2004) found that the characteristics of inhalant dependence were very similar to those found for the other substances. In particular, inhalants were similar to methamphetamine and alcohol and greater than nicotine in terms of subjective effects (pleasant feelings associated with the drug) and withdrawal (craving). The intensity of drug seeking was similar between inhalants, methamphetamine, and nicotine; alcohol was higher. In terms of social disturbance and particularly acute psychic and physical disorder, methamphetamines and inhalants showed the most significant influence, whereas nicotine showed the least. Although the focus of this study was primarily on determining how nicotine dependence relates to dependence on other drugs, it is evident that inhalants present similar clinical characteristics to other drugs of dependence.

Indeed, evidence is mounting that inhalants act on the same areas of the brain as do cocaine, amphetamines, and other addictive drugs. Recent animal studies have demonstrated that toluene, a solvent contained in gasoline, spray paint, and glue, enhances dopamine activity in the brain's pleasure center, the nucleus accumbens, in much the same way as do other drugs (Koob, 1992, 2002; Leshner & Koob, 1999; Wise, 1998; Wise & Bozarth, 1982, 1984; Riegel, Ali, Torinese, & French, 2004; Riegel et al., 2003; Riegel & French, 2002). Nonhuman primates lever-press to receive bursts of toluene vapor (Weiss, Wood, & Macys, 1979) just as they actively seek other addictive drugs. This evidence has led some researchers to conclude that inhalants fit squarely in the same category as other drugs of abuse (Riegel et al., 2003). To the extent that drug-seeking behavior in general is linked to a desire for the

euphoria associated with increased dopamine activity in the brain, it seems conceivable that inhalants could serve to introduce an individual to these sensations and increase the likelihood of future drug use.

2.9.2 Previous Studies on the Relationship between Inhalant Use and Other Drug Use

A growing body of evidence suggests a clear and consistent association between the use of inhalants and the use of other drugs. Several studies have suggested that inhalant use serves as a marker for other serious drug problems, such as cocaine, heroin, and intravenous drug use (Bennett et al., 2000; Dinwiddie, Reich, & Cloninger, 1991a; Johnson et al., 1995; Schutz et al., 1994; Novins & Baron, 2004). The majority of these studies have explored associations between inhalant use and other drug use or related behaviors using cross-sectional data, precluding an assessment of temporality. But evidence from these studies suggests that the early use of inhalants by adolescents may serve as a "red flag" for the development of later illegal drug use (Storr, Westergaard, & Anthony, 2005).

2.9.2.1 Longitudinal Studies

Only two identified studies have longitudinally investigated the role of inhalants in predicting subsequent use of other drugs (Johnson et al., 1995; Storr et al., 2005), although neither study examined the prospective relationships between adolescent inhalant use and the use of gateway drugs typically used earlier in drug use sequences. Johnson et al. (1995) found that African American youth living near Chicago with a history of any inhalant use by age 16 were more than nine times more likely to begin heroin use by age 32, after controlling for other risk factors, including marijuana use, dropping out of high school, alcohol use, cigarette use, family income during childhood, and adult area of residence. Notably, with marijuana and inhalants included in the multivariate model, cigarette and alcohol use—highly significant predictors in bivariate models—were no longer significant, suggesting that

any association between cigarettes/alcohol and later heroine use may be fully mediated by the intermediate use of inhalants and marijuana. The authors concluded that inhalants are an important marker for the development of later more serious drug involvement in the form of heroin use.

Because Johnson et al. (1995) focused on the specific prospective relationship between inhalants and heroin, while controlling for alcohol, tobacco, and marijuana use, relationships between these other drugs and inhalant use were not described. Thus, no conclusions regarding inhalants as a potential gateway drug were offered. Importantly, the sample included relatively few users of inhalants and heroin, yielding unstable relative risk estimates and wide confidence intervals. Indeed, inhalant use rates have consistently been lower for African Americans than for all other racial/ethnic groups (Wu et al., 2004). Furthermore, inhalant use was measured only at baseline, when the participants were an average age of 16. There is evidence that inhalant use peaks at an earlier age and that early inhalant use is particularly predictive of later illicit drug use (Storr, Westergaard, and Anthony, 2005).

Storr, Westergaard, and Anthony (2005) replicated and expanded upon Johnson et al. (1995) by examining estimates of relative risk of opiate use (heroin or opium) subsequent to the use of inhalants at an earlier age (14 years old) among a larger and more diverse sample of adolescents living in urban areas within a large metropolitan area. The findings were consistent with other studies showing that early inhalant use is associated with later heroin use or injection drug use (e.g., Dinwiddie, Reich, & Cloninger, 1991b; Johnson et al., 1995). Adolescents who used inhalants prior to age 14 were nearly three times as likely to start using heroin or opium by young adulthood compared with adolescents who had not used

inhalants by age 14, after controlling for gender, early signs of aggression and misbehavior, family social status, and race/ethnicity.

Storr, Westergaard, and Anthony (2005) further explored whether inhalant use was a unique predictor of excess risk of opiate use or whether early inhalant use is better conceptualized as part of a more general susceptibility trait, defined by the authors as early onset use of multiple drugs (alcohol, inhalants, tobacco, and marijuana). Comparing two nested structural equation models, they found that including early onset of inhalant use did not improve the fit of a model that included a direct regression path from opiate use to the early onset multiple drug use trait. The authors concluded that the link between early inhalant use and later opiate use may not reflect a direct causal link. Instead, early inhalant use could serve as an indicator of a more general susceptibility trait. Such a view would be concomitant with problem behavior theory (Jessor & Jessor, 1977) and other work on general susceptibility trait models (Morral et al., 2002).

Additional plausible interpretations of these study findings are evident. The approach directly tested whether early onset of inhalant use uniquely predicted later opiate use above and beyond the prediction provided by the general susceptibility measure. The fact that, when entered alone, early onset inhalant use led to an increased relative risk estimate and that this relationship disappeared when a general susceptibility trait was included in the model could suggest a mediated effect between inhalant use and later opiate use. It is possible that inhalants served as an initial or early marker of susceptibility. Although it appears that inhalants are one of the earliest drugs tried (Wu et al., 2004), no study to date has attempted to determine where in a drug use sequence inhalants belong. Early onset inhalant users may

be more likely to try other drugs early, subsequently placing them at higher risk for later illicit drug use. Results to date do not provide an adequate test of this possibility.

2.9.2.2 Nationally Representative Samples

Inhalant users appear to represent a group at particularly high risk for progression to substance use disorders and related problems. Wu, Pilowsky, and Schlenger (2005) used pooled nationally representative data from the 2000 and 2001 NHSDA to examine the likelihood of progression to substance use disorders among adolescents (ages 12 to 17) who used both marijuana and inhalants compared with those who used either marijuana or inhalants and those who used other drugs but not marijuana and inhalants.

Adolescent users of both marijuana and inhalants, who constituted 16% of all lifetime drug users in the sample, were much more likely to report lifetime use of most substances, a finding consistent with earlier studies (Novins & Baron, 2004; Novins et al., 2001). Ninety-seven percent of respondents in this group reported ever use of alcohol, compared with 91% in the marijuana only group, 60% in the inhalants only group, and 55% in the other drugs only group. The contrasts were even more striking for other substances. Twenty-seven percent of the marijuana and inhalants group had used cocaine/crack; the next highest prevalence was 7% in the marijuana only group. Prevalence rates in the marijuana and inhalants group were five times higher than in any of the other drug use groupings for heroin and two to three times higher for hallucinogens, sedatives, stimulants, and tranquilizers (Wu et al., 2005).

Among adolescents who reported any use of a drug in their lifetime, the prevalence estimates of past year alcohol and drug abuse were alarmingly high and significantly higher among adolescents who had used both marijuana and inhalants than among adolescents who

had used just one of the two drugs. Thirty-five percent of the lifetime marijuana and inhalants users reported past year alcohol dependence, and 39% reported past year drug use disorders. The next highest prevalence rates were found among the marijuana-only group, with 17% reporting alcohol disorders and 16% reporting drug disorders (Wu et al., 2005).

Also notable in this study was the very high prevalence of multiple drug use among users of both marijuana and inhalants. Within this group, 73% reported ever using three or more drugs. In a related study using the same NHSDA pooled data set (2000–2001), Wu, Pilowsky, and Schlenger (2004) found that 49% of adolescents who had ever used three or more classes of other drugs had ever used inhalants. Only 4% of lifetime inhalant users reported no use of other drugs, suggesting an important association between inhalant use and polydrug use (Wu et al., 2004). Taken in whole, these results from a nationally representative sample illustrate clearly that youth who use both marijuana and inhalants have the highest prevalence of alcohol and drug use disorders and lifetime polydrug use. Even after controlling for several known and suspected determinants of drug abuse and dependence, results from this study reveal that the use of both marijuana and inhalants may signal an early, heightened risk for serious alcohol and drug abuse and dependence (Wu et al., 2005).

As found in other national surveys (Johnston et al., 2005), the Wu et al. (2005) study found that inhalant use was more prevalent than marijuana or other drug use among young adolescents (aged 12 to 13 years), and the mean reported age at first inhalant use was also younger than for marijuana (11.8 years versus 13.8 years). Although it is not possible with these cross-sectional data to determine whether inhalant use typically precedes marijuana use among adolescents who use both, these data do provide some tantalizing evidence that inhalants may play an important role in a particularly serious form of drug use sequencing.

An earlier study based on data from the 1990 NHSDA focused on the relationship between inhalants and injection drug use (Schutz et al., 1994). Results controlling for a wide range of sociodemographic characteristics and history of marijuana use suggested that adolescents with a history of inhalant use were 5.4 times more likely to inject drugs. Similar to the findings from Wu, Pilowsky, and Schlenger (2005), the odds of injecting drugs were significantly increased for adolescents with a history of both inhalant and marijuana use: 88 times the odds relative to those who had never used either drug (Schutz et al., 1994).

Although the majority of youth who use inhalants give it up over time (chronic dependency appears to be rare), among the minority who do go on to regular inhalant use and dependence, a wide range of other problem behaviors are exhibited (Wu et al., 2004). In an analysis of data from 36,859 adolescents between the ages of 12 and 17 from the 2000 and 2001 NHSDA, Wu et al. (2004) found that adolescents with inhalant abuse diagnoses were significantly more likely to have already abused inhalants by age 13 or 14 and to have abused two or more other drugs besides inhalants. Compared to youth with no abuse of inhalants, youth with an abuse disorder (defined by the DSM-IV as having one or more inhalant-related problems in the past year but not meeting the criteria for dependence) were 5 times more likely to have used two other illegal drugs in the past year and 18 times more likely to have used three other illegal drugs. Youth classified as having a dependence disorder (defined as having three or more drug-related problems in the past year) were 12 times more likely to have used two other drugs and 24 times more likely to have used three other drugs in the past year. Although these data were cross-sectional and the findings associative rather than prospective, it is clear that inhalants play a potentially important role in adolescent drug use patterns.

Among youth aged 12 or 13 interviewed for the 2003 NSDUH who had used inhalants in their lifetimes, 35.4% had used another illicit drug, compared with 7.5% of youth in this age group who had never used inhalants (SAMHSA, 2005). Further evidence of the potential role of early inhalant use in drug use pathways comes from retrospective studies of adults aged 18 to 49 interviewed for the 2002 and 2003 NSDUH. Adults who reported early use of inhalants (before age 13) were more than three times more likely to be classified with dependence on or abuse of alcohol or an illicit drug in the past year than adults who had never used inhalants (35.2% versus 10.1%) (SAMHSA, 2005).

According to 2002 NSDUH data, adolescents who reported past year inhalant use were 3 times more likely to report using other illicit drugs during the same period (SAMHSA, 2003). The association between past year inhalant use and the use of the most serious illicit drugs (hallucinogens, cocaine, and heroin) is even more pronounced. Adolescents who had used inhalants in the past year were more than 7 times more likely to have used hallucinogens (22.6% versus 3.0%) and cocaine (12.5% versus 1.6%) than adolescents who had not used inhalants. Although overall past-year heroin use is low, adolescents who reported past-year inhalant use were 17 times more likely to report heroin use during the same period than adolescents who did not (SAMHSA, 2003).

These results suggest that inhalant use may be an important potential marker for other serious illicit drug use. Indeed, among this sample, heroin and cocaine use was nearly nonexistent among youth who had not also used inhalants. These data are cross-sectional, precluding sequential analyses. However, the fact that past-year inhalant use in this survey peaked at age 14 or 15 (4.9%) and that data from the 2003 NSDUH indicate that a higher percentage of youth aged 12 or 13 had used inhalants than marijuana in the past year

(SAMHSA, 2004), suggests that inhalants may be one of the earliest drugs used by lifetime polydrug users.

2.9.2.3 Clinical and Special Population Samples

A study of substance use among college students (Bennett et al., 2000) compared early (prior to age 18) inhalant users with early marijuana users who did not use inhalants and students who reported no early use of either marijuana or inhalants. Both early inhalant users and early marijuana users were substantially more likely to report early use of cocaine, opiates, and hallucinogens. The rates of early use of these drugs were two to three times greater for early inhalant users than for early marijuana users, and early inhalant users consistently showed the highest rates of problematic patterns of drinking and substance use and of recent (past year and past month) cigarette smoking, marijuana use, and other illicit drug use. Among this sample of college students, inhalants were associated with greater use rates and odds ratios for alcohol and drugs during the college years, above and beyond the association with early marijuana use (Bennett et al., 2000).

Notably, this study did not include a group classification for early users of both inhalants and marijuana (Wu et al., 2005), although the early inhalant use group did not exclude early marijuana use (or early use of other drugs). Thus, this study does not provide solid evidence that inhalants represent a unique risk for later drinking and drug use. Moreover, the data from this study relied on retrospective recall to define the early use of inhalants and marijuana. Early inhalant use was surprisingly low in this population (5.2%). A consistent finding from nationally representative studies is that reported lifetime use rates for inhalants decline as adolescents age, suggesting that older respondents forget or consciously

deny early use of inhalants, which may have occurred several years prior to assessment (Johnston et al., 2005).

Very few nationally representative studies of adolescent inhalant use have been conducted. Much of what is known about inhalant use and the apparent association between inhalant use and other drug use has come from studies of clinical samples, primarily adolescents and/or adults in treatment programs for substance and behavior problems. For example, Sakai et al. (2004, 2006) considered inhalant use and dependence among adolescents ages 13 to 19 in a residential day treatment program, finding that inhalant use was strongly associated with other substance abuse and dependence (alcohol, hallucinogens, nicotine, cocaine, and amphetamines) and with criteria for lifetime major depression, previous suicide attempts, and conduct disorder. Notably, the authors found no significant differences in these variables between inhalant users and individuals meeting DSM-IV criteria for inhalant dependence (Sakai et al., 2004). In contrast to other national and clinical sample studies (e.g., Wu et al., 2005; Young et al., 1999; Novins et al., 2001), inhalant use in this small clinical sample occurred late in relation to nicotine, alcohol, and marijuana, leading the authors to conclude that inhalants do not serve as a gateway drug in most cases but that the use of inhalants at any time may indicate a particularly high-risk profile (Sakai et al., 2004, 2006).

A cross-sectional study of a sample consisting of adult alcoholics, felons, and a control group (Dinwiddie, Reich, & Cloninger, 1991a) produced similar results, where significant proportions of users of any drugs reported early inhalant use, and 93% of those who reported early inhalant use had used three or more classes of drugs. Inhalant users in this sample began using drugs earlier, and the use of inhalants increased the odds of other drug

use by 5 to 10 times. Because this study relied on retrospective recall and the sample was clinical and nonrepresentative, these findings should be viewed with caution. However, the findings add support for an important association between inhalants and the use of other drugs.

A study of adolescent inmates in a juvenile detention facility found, in contrast with Sakai et al. (2004), that even among a particularly high-risk sample, inhalants were the substance with the earliest first reported use, an average age of 9.7 years (Young et al., 1999). Young et al. (1999) also found that the traditional gateway sequence, beginning with alcohol and tobacco, progressing to marijuana, and then to cocaine, hallucinogens, and opiates, operated within this sample. However, among the subsample of youth who had used inhalants, this was the first class of drug used, preceding cigarettes by 1.5 years. This study is one of the only identified that directly seeks to identify the location of inhalants within the gateway drug use sequence. However, its cross-sectional design and reliance on retrospective recall of age of first use introduces potential recall bias and precludes any assessment of actual transitions from the use of one class of drugs to another.

2.9.3 Summary of Evidence of a Gateway Relationship between Inhalants and Other Drugs

Taken together, evidence from longitudinal, nationally representative, and clinical research suggests a potential gateway relationship between inhalants and other drugs. Given that inhalants are typically tried during late childhood or early adolescence, it appears that inhalants commonly precede the use and abuse of other drugs. Inhalants produce effects that are physiologically, neurologically, and qualitatively similar to other drugs, and given that inhalants are widely available and easily accessed by young adolescents, it is plausible that inhalants may serve as an initial entrée into drug use. While the question of whether inhalant

use actually predicts future drug use patterns remains largely untested, some feel that the evidence in favor of inhalants as a gateway drug is clear: “As the new gateway drug, it is critical that research and prevention efforts pay special attention to the etiology of inhalant use” (Edwards & Oetting, 1995, p. 26).

CHAPTER 3

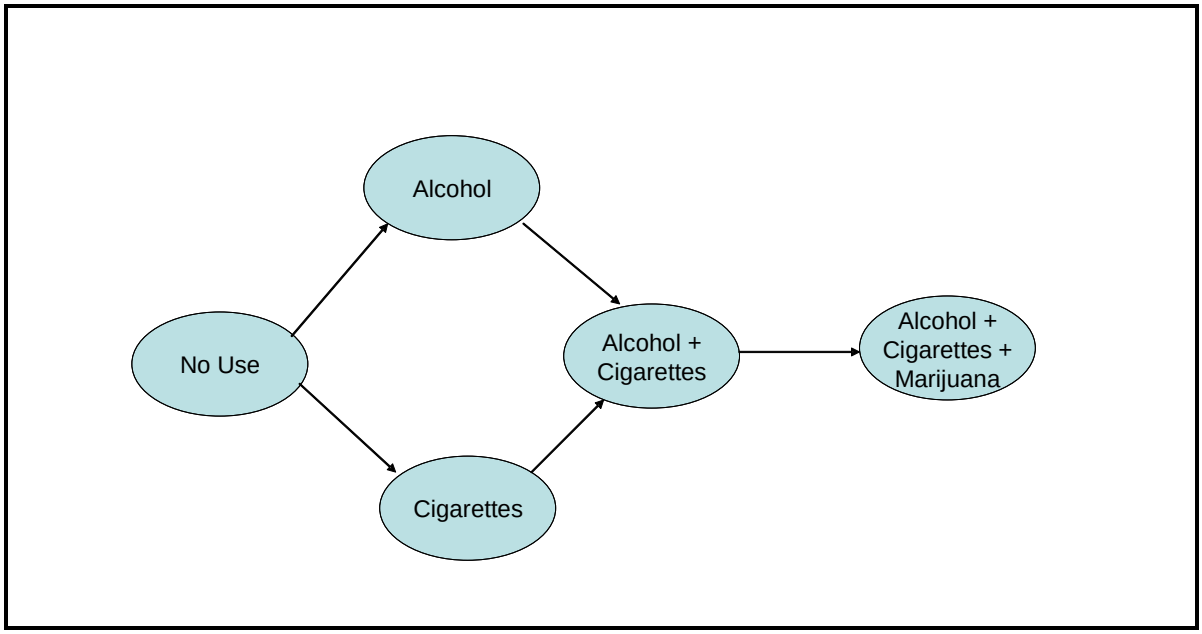
DISSERTATION RESEARCH QUESTIONS AND HYPOTHESES

1. ***Can the gateway hypothesis be extended to include inhalants for African American and white, male and female adolescents in grades 6 through 8?***

Latent transition analysis (LTA) is used to identify the stages and transitions of drug use onset that best fit the patterns present in the data for this study sample of African American, white, male, and female adolescents in grades 6 through 8 from (primarily rural) North Carolina.

Although a general model of gateway drug use involving alcohol, cigarettes, and marijuana (Figure 3.1) has been widely described (Kandel & Yamaguchi, 2002; Kandel, 1975, 2002; Collins, 2002; Kandel et al., 1992; Yamaguchi & Kandel, 1984a; Kandel & Faust, 1975; Ellickson et al., 1992), the potential role of inhalants in drug use sequencing has not been formally assessed. For this reason, models of gateway drug use that include inhalants are estimated and compared to determine (a) whether inhalants "belong" in the gateway sequence and (b) which model best fits the data.

Figure 3.1 General Model of Gateway Drug Use

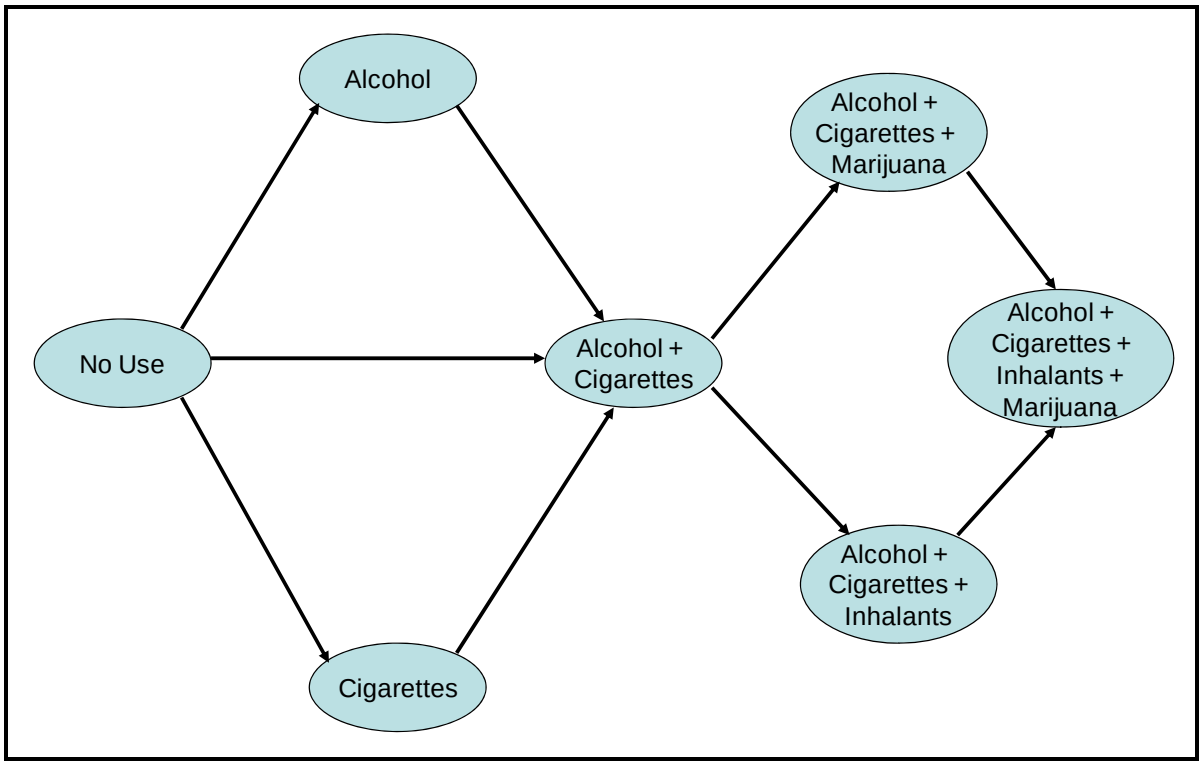


The literature on inhalants and adolescent drug use, although not extensive, suggests that early adolescent inhalant use may be an important stage in drug use progression for some adolescents. Inhalants produce effects similar to alcohol and other drugs and have been shown to operate on the same areas of the brain. Inhalants are one of the earliest drugs tried and the most widely available class of drug, present in most households or available for legal purchase. Proponents of the gateway hypothesis and common liability theories both maintain that the wide availability of alcohol and tobacco at least in part explains their gateway role; a similar relationship may exist between inhalants and drug use progressions.

For instance, it is possible that, for a proportion of adolescents, initiating inhalant use will precede, and increase the likelihood of transitioning to, marijuana use. A general representation of this alternate model, presented in Figure 3.2, includes seven discrete stages of drug use: (1) never use; (2) alcohol only; (3) cigarettes only; (4) alcohol and cigarettes; (5)

alcohol, cigarettes, and marijuana; (6) alcohol, cigarettes, and inhalants; and (7) alcohol, cigarettes, inhalants, and marijuana.

Figure 3.2 Possible Drug Use Onset Model Including Inhalants



This model revises the traditional gateway model by adding two stages, thus positing that seven drug use stages best represent the onset process among adolescents and that inhalant use is an important component of adolescent drug use sequencing. This hypothetical model suggests that there is a subpopulation of adolescents, those who experiment with inhalants, who follow a slightly modified gateway process and for whom inhalants act as a gateway to marijuana use. LTA is used to identify the stages and transitions that best represent the data.

There is reason to suspect that gateway drug use models that include inhalants may differ between male and female and between African American and white adolescents. For

instance, whereas male and female adolescents appear to have very similar rates of inhalant use, females typically have lower rates of use for other drugs. This suggests that inhalants may be more important for females than males. Moreover, recent evidence suggests that inhalant use is increasing among females while remaining stable among males (Substance Abuse and Mental Health Services Administration [SAMHSA], 2007).

African American adolescents typically report lower rates of drug use than whites in nationally representative surveys, and this is true for inhalants as well. While a good deal of early research on the gateway hypothesis has suggested that the general sequence is typically robust across racial/ethnic groups (e.g., Yamaguchi & Kandel, 1996), it remains unclear and untested whether drug use sequencing is consistent across these groups when inhalants are considered. African American adolescents may have lower prevalence rates for each drug but still follow the same general drug use sequence as white adolescents; conversely, the number and type of drug use stages may be distinctly different for African Americans.

To determine whether the same model of drug use sequencing fits across gender and for both African American and white samples, the process of model selection was first conducted separately for each of the four subsamples: (1) white males, (2) white females, (3) African American males, and (4) African American females. As noted earlier, inhalant use is significantly more prevalent among white adolescents than African American adolescents, suggesting that analyses of drug use sequencing that includes inhalant use may differ by race. Similarly, relative to males and in comparison to other drug use, inhalant use is particularly prevalent among female adolescents; it is possible that inhalants may serve a more prominent role in drug use sequencing for females. These potential differences would be obscured if the analyses were conducted on the full sample.

The following main hypotheses related to research question one were tested:

1. *Hypothesis 1.1:* Inhalant use will precede marijuana use for a significant number of adolescents.
2. *Hypothesis 1.2:* The probability of transitioning from inhalant use to marijuana use is significantly greater than the probability of transitioning from marijuana use to inhalant use, suggesting a partial gateway relationship.
3. *Hypothesis 1.3:* Drug use sequencing models will differ by race and gender; inhalants will play a more important role for white and female adolescents.

2. Does the probability of transitioning from inhalant use to other drug use remain after controlling for demographic factors and key psychosocial predictors of adolescent drug use?

Critics of the gateway hypothesis argue that, although it is clear that most drug users begin their use with gateway drugs like alcohol, cigarettes, and marijuana, there is limited or equivocal evidence suggesting that the use of a gateway drug independently increases the likelihood of using other drugs. True experimental designs would be required to assess questions of causality, but these designs are not feasible (or ethical) in the case of drug use.

In lieu of an experimental design, three criteria for assessing the causal influence of the use of one drug on the use of other drugs have been proposed (Kandel & Jessor, 2002). The first criterion is evidence that those who use a drug or drugs are significantly more likely to have used the supposed gateway drug. The second criterion is evidence that the use of the gateway drug typically precedes the use of the other drugs; the probability of transitioning from the gateway drug to the other drug(s) should be significantly greater than the probability of transitioning from the use of the later drug(s) to the supposed gateway drug (Maldonado-Molina, 2005).

The third criterion is evidence that the association between early gateway drug use and later other drug use remains significant after controlling for potentially confounding variables, particularly factors that might be common causes of both gateway and later drug use. No identified studies have investigated inhalants as a gateway drug, and few studies have explored whether the transition probabilities between drugs remain after controlling for the influence of potentially confounding variables thought to represent common liabilities for drug use (Rebellon & Van Gundy, 2006; Tarter et al., 2006).

The number and variety of potential variables that could plausibly explain drug use behaviors is large, and an attempt to control for all possible predictors is beyond the scope of this study. However, several key factors cited by proponents of a "common cause" explanation of drug use, and based in large part on Problem Behavior Theory (Jessor, 1991), are apparent. These include perceived drug availability, perceived peer drug use and attitudes, parental disapproval of drug use, academic achievement, and an individual's propensity to engage in sensation-seeking and risky/delinquent behavior.

The LTA approach applied to the primary research questions above provides a flexible approach for examining patterns of drug use over time and for testing hypotheses about the order of progression between drugs and the transition probabilities from one drug use stage to another. Recent enhancements to LTA software also make it feasible to assess whether transition probabilities between inhalant use and other drug use persist after controlling for other factors.

A final model for white females was identified and selected that included a transition between an inhalant use stage and a marijuana use stage, facilitating an "LTA with covariates." In this framework, covariates representing demographic and psychosocial factors

thought to represent liabilities for drug use (Tarter et al., 2006) were added to the model explicitly as predictors of the transition probability from inhalant use to other drug use. If inclusion of the covariates causes a substantial decrease (toward zero) in the transition probability, then this would be evidence that the transition probability is largely the effect of covariates, rather than a direct effect of inhalants. Conversely, if the transition probability remains after controlling for the covariates, then this would be compelling evidence that the relationship between inhalants and other drugs is indeed predictive. The following main hypothesis was tested:

1. *Hypothesis 2.1:* The probability of transitioning from inhalant use will remain after controlling for baseline drug use, demographic factors, and common liability variables.

CHAPTER 4

METHODS

4.1 Study Design

This research is a secondary analysis of data derived from the Context of Adolescent Substance Use Study (Context Study) (NIDA Grant No. R01 DA16669, UNC IRB #99-830). The Context Study is a cohort-sequential study of adolescents followed from grades 6, 7, and 8 to grades 8, 9, and 10. The dissertation study sample includes all white and African American adolescents who completed a survey during at least one of five data collection times and for whom data were available for at least grades 6 or 7. The data used for this dissertation were coded and de-identified to ensure participant confidentiality. This dissertation research was determined to be exempt from institutional review board (IRB) approval by the University of North Carolina at Chapel Hill, Office of Research Ethics, IRB (UNC IRB #: 06-0483).

4.2 Overview of the Context of Adolescent Substance Use Study

The Context Study is a longitudinal investigation of intrapersonal and contextual factors that influence adolescent substance use and other problem behaviors. This school-based study involved adolescents from the public schools in three counties in North Carolina classified as nonmetropolitan areas, with lower than average median household incomes and with greater proportions of African Americans than in the general U.S. population.

The Context Study used a cohort-sequential design, wherein three grade cohorts (grades 6, 7, and 8 at first assessment) were assessed twice annually. Data collection began in spring 2002 and ended in spring 2004.

Unlike standard longitudinal and cross-sectional designs, a cohort-sequential design allows for the modeling of longitudinal sequences covering a wide range of ages during a condensed study time frame (Andrews, Tildesley, Hops, Duncan, & Severson, 2003). In the case of the Context Study, data from five grades (6 through 10), with ages ranging from 11 to 17, are available.

4.3 Adolescent Sample and Data Collection

Adolescents enrolled in three public school systems in North Carolina were entered into the study in spring 2002, when they were 6th, 7th, and 8th graders, and completed the study as 8th, 9th, and 10th graders, respectively. The school systems were in three predominantly rural counties. The sample frame included eight middle schools, two comprehensive K–8 schools, six high schools, and three alternative schools with middle and high school grades. The high schools were not included until Wave 2 when the first 8th graders transitioned from middle school. Data collection was timed to coincide with the beginning and end of the school year. At each data collection wave, all enrolled students at the targeted grade levels, except for those in self-contained classrooms for students with limited English language reading skills, were eligible for the study. Thus, students new to the study were enrolled at each wave of data collection. Across the five assessments, a total of 6,891 unique cases completed the survey. Response rates at the five waves were 88.4%, 81.3%, 80.9%, 79.1% and 76.0%, respectively (Table 4.1).

Table 4.1 Context Study Questionnaire Administration

Wave	1	2	3	4	5
Date	Spring 2002	Fall 2002	Spring 2003	Fall 2003	Spring 2004
Grades	6, 7, 8	7, 8, 9	7, 8, 9	8, 9, 10	8, 9, 10
No. schools	13	19	19	19	19
Adolescent survey	N = 5,220 (88.4%)	N = 5,060 (81.3%)	N = 5,059 (80.9%)	N = 5,017 (79.1%)	N = 4,676 (76.0%)

Parents could refuse their child's participation by calling a toll-free number or mailing a refusal form. Written assent was obtained in school from adolescents by trained data collectors who also provided instructions.

School-based data collection was scheduled in advance, and at least one makeup day for absentee students was scheduled each wave at each school. Trained data collectors followed a written protocol for describing the study, obtaining assent, and giving instructions for completing the adolescent questionnaires. Adolescents completed the self-administered questionnaire in classrooms or larger group settings (e.g., cafeteria) in approximately 1 hour. Teachers stayed in classrooms to help maintain order, but they did not answer questions about the study or walk around the classroom. To ensure privacy, data collectors spread the students around the classroom and instructed students not to talk with each other. Students put their questionnaires in envelopes before returning them to the data collectors.

4.4 Analysis Samples

Original data for the Context Study were organized by study wave. The Context Study used an accelerated cohort design in which three grade-based cohorts was followed for a constant period of time. For this study, data were reshaped to represent grade-in-school, a more natural and more clearly interpreted temporal measure that is consistent with literature on adolescent development (Singer & Willett, 2003). The Context Study includes five waves

of data, collected twice a year, once in the spring and once in the fall (see Table 4.1). Data from Waves 2 and 3 and from Waves 4 and 5 were collapsed to represent a school year. Because respondents initially vary in grade, observed measurement occasions will differ across individuals. As illustrated in Table 4.2, not only are 6th graders potentially re-interviewed at 7th and 8th grades, but concurrent samples of 7th and 8th graders were potentially re-interviewed at grades 8 and 9 and grades 9 and 10, respectively. The advantage of this design is that it allows for the modeling of change over a longer temporal period using fewer waves of data (Singer & Willett, 2003). However, because there is no overlap at the earliest and latest grades (only one cohort is interviewed for these grades), data are sparser at these grades.

Table 4.2 Cohort Sequential Design of the Context Study

	Grade				
Wave	**6**	**7**	**8**	**9**	**10**
1	2,017	1,874	1,709	—	—
2 & 3	—	1,759	1,629	1,511	—
4 & 5	—	23	1,718	1,511	1,243
Total	2,017	3,656	5,056	3,022	1,243

Note: Waves 2 & 3 and 4 & 5 were combined to represent school years.

An original total sample of 6,891 adolescents participated at any wave of data collection. Students who were outside the typical age range of 11 through 17 years for the grades studied (n = 66, 1%) or who did not respond to any of the substance use measures at any time point (n = 4, 0.1%) were excluded, yielding a sample size of 6,821 (99%) for the entire study period.

From this sample, African American (N = 2,431) and white (N = 3,435) adolescents were selected for inclusion; all others were dropped from the analysis sample. This yielded a sample of 5,866 respondents—85.1% of the original full sample. Finally, because this study

focused on transitions from 6th to 7th grade and from 7th to 8th grade, the sample was restricted to adolescents for whom data were available for at least 6th or 7th grade ($N = 3,414$).

These analyses focus on four subsamples: white males, white females, African American males, and African American females, with two transition periods (6th to 7th grade and 7th to 8th grade). Therefore, a total of eight analysis subsamples were created. For each of the four 6th–7th grade data sets, only participants who responded to any of the substance use measures in 6th grade (baseline) were included ($N = 1,630$). Similarly, participants who responded to any of the substance use measures in 7th grade ($N = 3,344$) were included for the four 7th–8th grade data sets. Table 4.3 provides sample sizes and mean ages for the adolescents in each subsample.

Table 4.3 Analysis Samples: Sample Size, Mean Age, and Attrition (%)

Sample	N	Mean Age at Baseline (SD)	Attrition[a] (%)
6th–7th grade			
White males	464	12.12 (.54)	2.8%
White females	464	11.97 (.45)	3.0%
African American males	363	12.46 (.89)	7.4%
African American females	339	12.21 (.65)	4.7%
Total	1,630	12.17 (.66)	4.3%
7th–8th grade			
White males	955	13.13 (.57)	6.2%
White females	954	12.98 (.46)	4.4%
African American males	703	13.47 (.83)	8.4%
African American females	732	13.24 (.70)	5.6%
Total	3,344	13.18 (.66)	5.7%

[a] Attrition refers to the percentage of respondents present at baseline who were lost to follow-up at Time 2. LTA allows for missing data via a full-information maximum likelihood technique, so all cases are included in the analyses.

4.5 Measures

4.5.1 Drug Use Onset

Four substance use items (lifetime alcohol, lifetime cigarette, lifetime inhalant, and lifetime marijuana) were used to measure an individual's lifetime substance use stage. Items with multiple response options were recoded as dichotomous, and all items were recoded using a numbering scheme required by WinLTA and SAS PROC LTA, the software used for the study analyses. Table 4.4 presents the wording of the original items (manifest variables) and the coding scheme used for analysis.

Table 4.4 Manifest Variables Measuring Latent Substance Use Onset

		Item Coding	
Drug Use Measure	**Question Wording**	**Original Coding**	**Revised (dichotomized) Coding for WinLTA[a]**
Ever used alcohol	How much alcohol have you ever had in your life?	0 = None at all, not even a sip 1 = 1 or 2 sips, but not a whole drink 2 = 3 or more sips, but not a whole drink 3 = 1 to 2 whole drinks 4 = 3 to 4 whole drinks 5 = 5 to 10 whole drinks 6 = 11 to 20 whole drinks 7 = More than 20 whole drinks	(Ever drank one or more sips) 0 = Missing 1 = No 2 = Yes
Ever used cigarettes	How much have you ever smoked cigarettes in your life?	0 = None at all, not even a puff 1 = 1 or 2 puffs, but not a whole cigarette 2 = 3 or more puffs, but not a whole cigarette 3 = 1 to 2 whole cigarettes 4 = 3 to 5 whole cigarettes 5 = 6 to 20 whole cigarettes 7 = More than 20 whole cigarettes	(Ever smoked one or more puffs) 0 = Missing 1 = No 2 = Yes
Ever used inhalants	Have you ever used any of the following in your life?...Inhalants	0 = No 1 = Yes	0 = Missing 1 = No 2 = Yes
Ever used marijuana	Have you ever used any of the following in your life?...Marijuana	0 = No 1 = Yes	0 = Missing 1 = No 2 = Yes

[a] For SAS Proc LTA, coding is as follows: "." = "missing," 0 = "No," and 1 = "Yes."

Table 4.5 and Figures 4.1, 4.2, and 4.3 present prevalence estimates for the four drug use measures. Although white females have significantly lower prevalence estimates for 6th and 7th grade alcohol, cigarette, and marijuana use than white males, the prevalence of inhalant use is roughly equal. Additionally, inhalant use appears to increase throughout the study period (6th to 8th grade) for white females, whereas it plateaus in the 7th grade for the three other samples. Inhalant use at the 6th grade is significantly more prevalent than marijuana use for both white males and white females; marijuana use is more prevalent at the 6th grade for African American males.

Table 4.5 Drug Use Prevalence (%), by Grade

	White Males			White Females			African American Males			African American Females		
	6th	**7th**	**8th**	**6th**	**7th**	**8th**	**6th**	**7th**	**8th**	**6th**	**7th**	**8th**
Ever drank alcohol	45.3 (42.6, 47.9)	57.6 (55.8, 59.4)	64.1 (62.7, 65.5)	35.7 (33.2, 38.3)	55.1 (53.3, 57.0)	67.5 (66.1, 68.9)	37.1 (34.2, 40.1)	45.3 (43.2, 47.5)	52.8 (51.0, 54.6)	35.2 (32.2, 38.3)	52.8 (50.7, 54.9)	63.8 (62.1, 65.5)
Ever smoked a cigarette	27.1 (24.7, 29.5)	37.5 (35.7, 39.2)	44.8 (43.3, 46.3)	17.3 (15.3, 19.4)	33.3 (31.5, 35.0)	43.8 (42.4, 45.3)	31.9 (29.0, 34.7)	44.9 (42.7, 47.0)	50.5 (48.7, 52.3)	23.9 (21.2, 26.5)	45.3 (43.2, 47.4)	55.6 (53.8, 57.3)
Ever used inhalants	10.0 (8.4, 11.6)	14.7 (13.4, 16.0)	15.2 (14.1, 16.2)	9.5 (8.0, 11.1)	13.7 (12.4, 14.9)	17.7 (16.6, 18.9)	8.4 (7.8, 10.1)	11.9 (10.5, 13.3)	12.0 (10.9, 13.2)	7.7 (6.1, 9.4)	11.7 (10.3, 13.0)	11.5 (10.4, 12.7)
Ever used marijuana	6.5 (5.2, 7.8)	14.4 (13.1, 15.7)	21.1 (19.9, 22.3)	3.0 (2.1, 3.9)	8.2 (7.2, 9.2)	17.0 (15.9, 18.1)	11.9 (10.0, 13.9)	23.9 (22.0, 25.7)	35.1 (33.4, 36.9)	5.4 (4.0, 6.8)	15.8 (14.3, 17.4)	26.7 (25.2, 28.3)

Note: 95% confidence intervals are shown in parentheses.

Figure 4.1 Overall Drug Use Prevalence, 6th–8th Grade

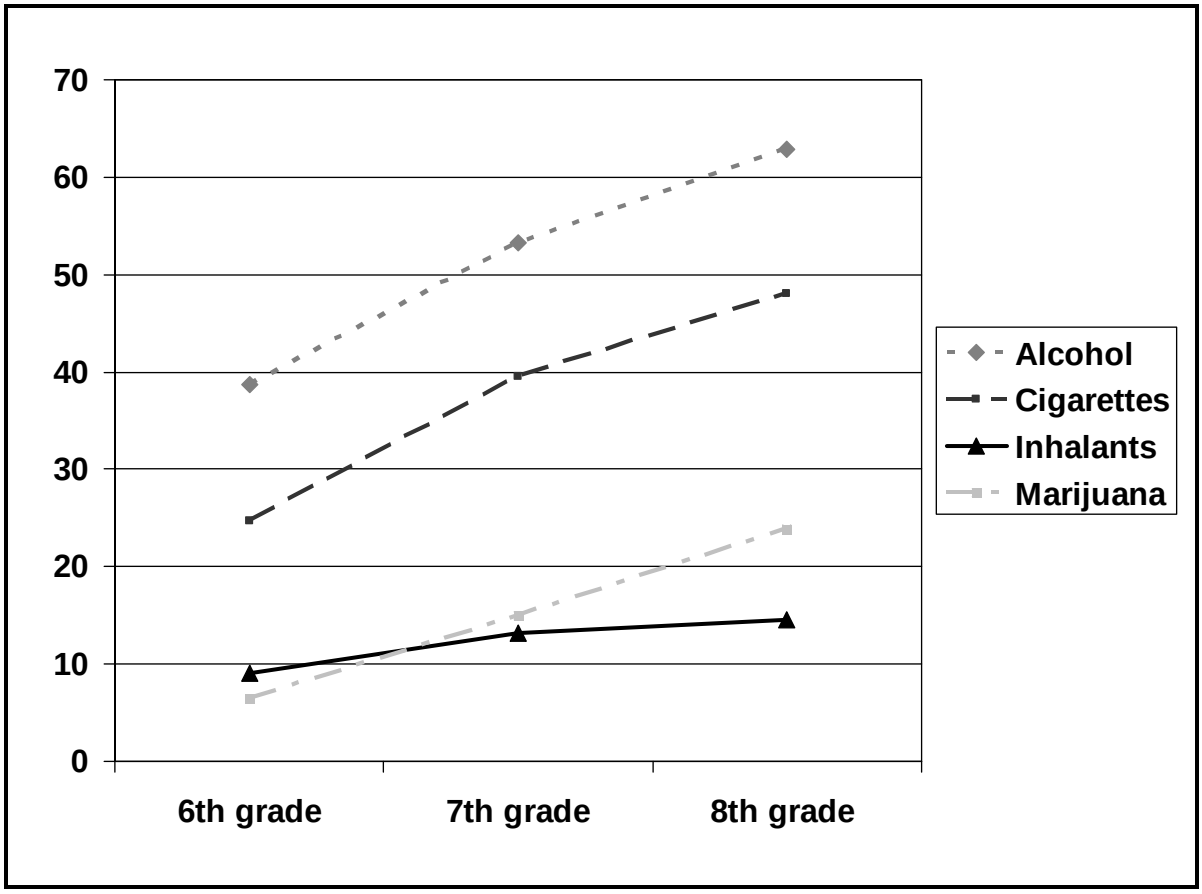


Figure 4.2 Prevalence for Each Drug, by Race/Gender, 6th–8th Grade

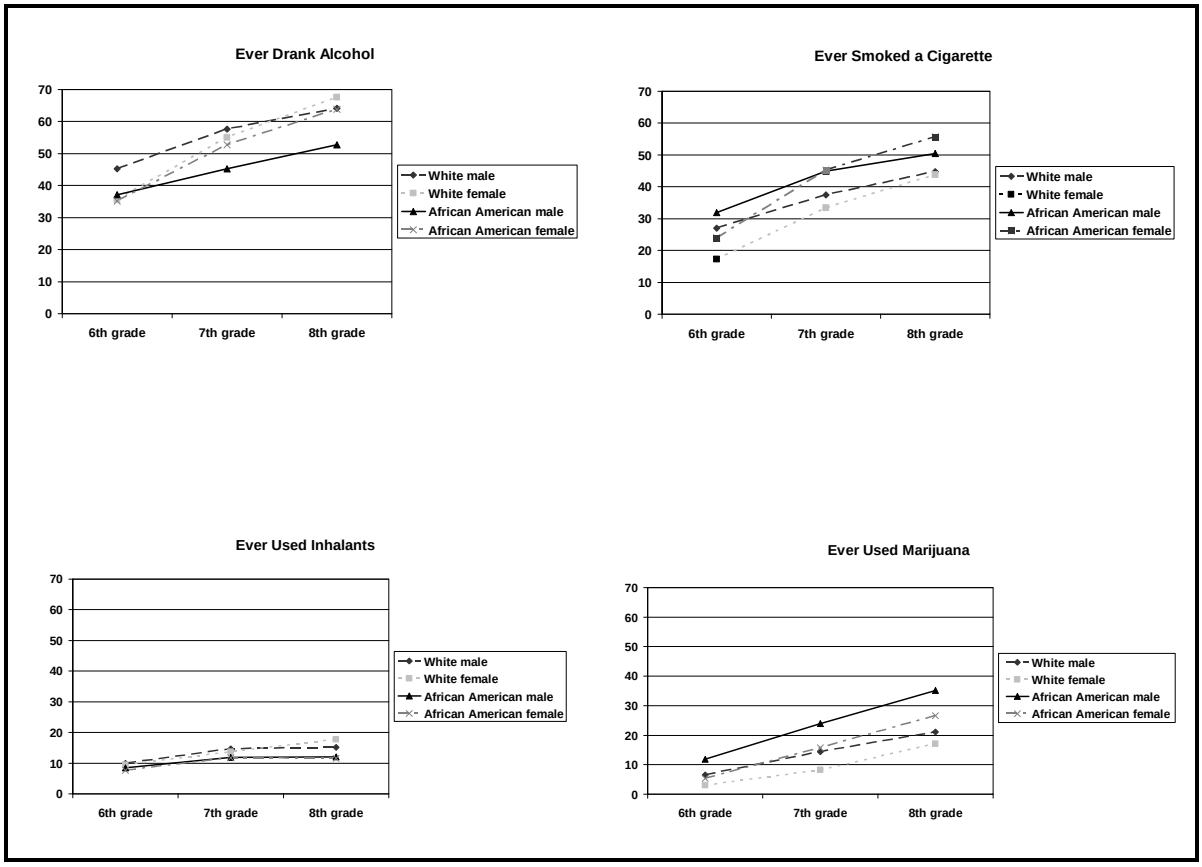
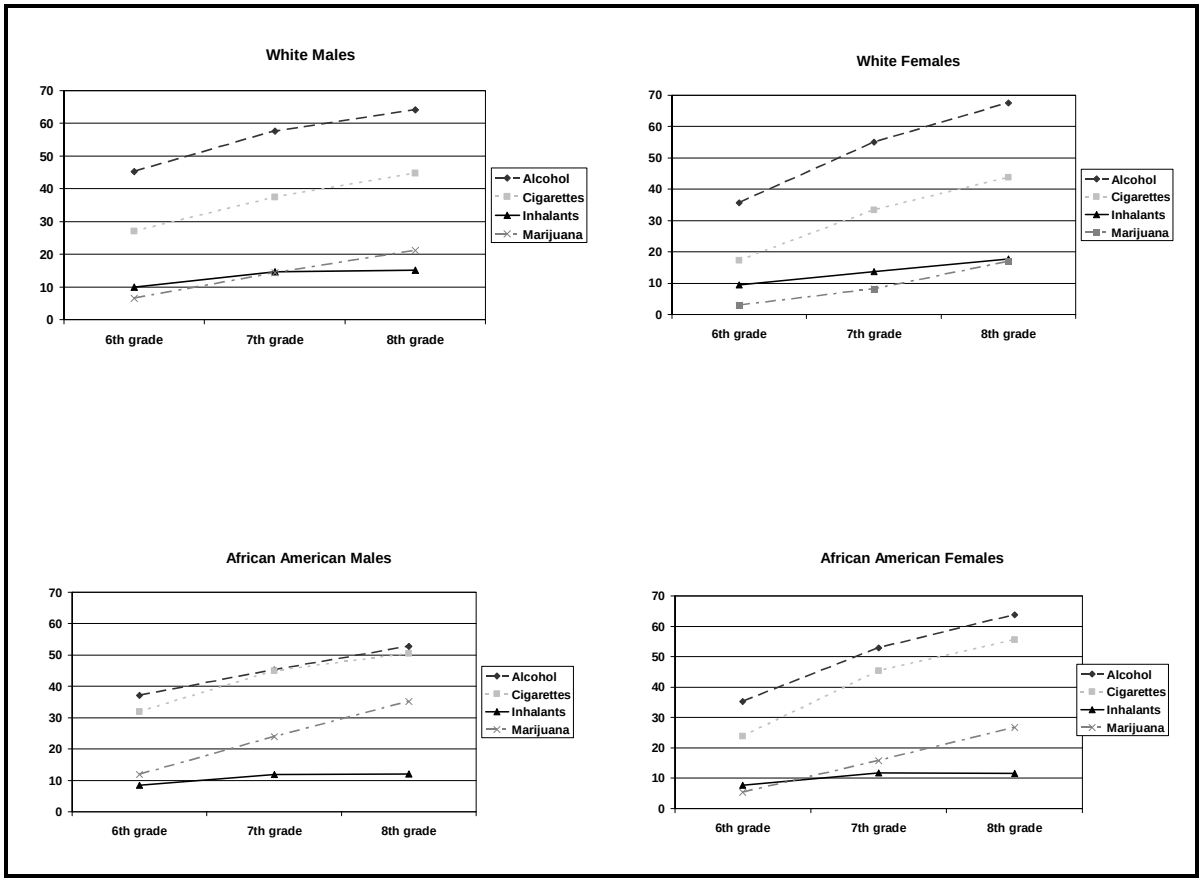


Figure 4.3 Drug Use Prevalence for Each Race/Gender Group, 6th–8th Grade



Response inconsistency is a common issue in longitudinal data. A particular form of response inconsistency, recanting, refers to cases where an individual denies a behavior after having admitted to it previously. Recanting is a common issue in longitudinal studies (Fendrich, 2005; Fendrich & Rosenbaum, 2003), and there is evidence that adolescents are more likely to recant on questions dealing with particularly stigmatized behaviors, including inhalant use and hard drug use (Percy, McAlister, Higgins, McCrystal, & Thornton, 2005). Differential rates of recanting could in part explain why inhalant use rates do not follow the trend of greater prevalence over time that the other drugs exhibit—older adolescents who may have reported inhalant use at an earlier age may no longer admit to inhalant use at a later age.

Indeed, an analysis of the longitudinal response patterns to these items confirms the high degree of recanting present in the data, particularly for the inhalant use item (Table 4.6). Among respondents who ever reported using a drug during the study period and who had an opportunity to recant after first reporting use of that drug (e.g., were present at a subsequent survey administration), and across the four samples and two transition periods, the rate of recanting for the inhalant use item ranged from 28.5% (among white females in the 7th–8th grade sample) to 51.8% (among African American females in the 7th–8th grade sample). For the total sample, 47.1% recanted for inhalants, 21.9% recanted for marijuana, 17.4% recanted for cigarettes, and 16.4% recanted for alcohol.

Table 4.6 Percentage of Respondents Recanting[a] Previous Self-Reported Drug Use

	White Males		White Females		African American Males		African American Females	
	6th–7th	7th–8th	6th–7th	7th–8th	6th–7th	7th–8th	6th–7th	7th–8th
Ever drank alcohol	8.3	11.5	4.9	6.5	19.7	20.3	13.5	10.9
Ever smoked a cigarette	10.7	13.8	2.6	6.1	17.3	18.7	6.3	13.0
Ever used inhalants	32.6	34.3	38.6	28.5	40.0	38.6	50.0	51.8
Ever used marijuana	13.3	19.0	28.6	16.7	21.4	14.5	44.4	16.5

[a] Recanting is defined as stating "never used" when the respondent indicated "ever use" at baseline.

In the drug use onset modeling, transition probabilities are restricted to forward-moving only. In other words, once a respondent indicates having ever tried a drug, movement back to a "never-use" stage is not permitted. Conceptually, the latent variable approach will treat responses that are inconsistent with this pattern as measurement error, highlighting an important advantage of this approach over traditional approaches. Given the high rates of recanting and subsequently inflated standard errors, estimates of inhalant use are likely to be extremely conservative.

4.5.2 Independent Variables

The second research question examined the strength of the relationship between inhalant use and subsequent drug use transitions by controlling for other factors that may predict drug use transitions. The data set used for this study included a wide range of psychosocial variables and scales that measure constructs that have been empirically and theoretically linked to adolescent substance use, offering the opportunity to control for a wide range of possibly competing factors.

Because these items were included in multivariate models, they were recoded so that higher scores indicate greater risk for all of the included variables. For instance, on a measure of the respondent's mother's degree of disapproval of drug use, the variable was recoded so that higher scores indicate lower degrees of disapproval. Age (a continuous measure) was included to control for possible heterogeneity of age within grades.

This second analysis depends on the identification, in analysis 1, of a model (or models) that includes a transition from inhalant use to a more advanced drug use stage. In other words, it is possible that the second analysis will be limited to fewer than the four samples (if inhalants are not included in the selected transition model for a sample). Therefore, frequencies and any necessary data transformations for these covariates are reported in Chapter 5 (Results), specifically for samples that pertain to analysis 2. Each of the covariate measures is described briefly below.

4.5.2.1 Risk-Taking Propensity

Sensation seeking. A sensation-seeking scale was created from three items (Grasnick, Tittle, Bursik, & Arneklev, 1993). Respondents were asked to indicate the degree to which they agree or disagree with the following statements: "I like to test myself every now and then by doing something a little risky," "I sometimes find it exciting to do things for which I might get in trouble," and "Excitement and adventure are more important to me than security." Scale reliability (Cronbach's alpha) for this scale ranged from $\alpha = 0.78$ to $\alpha = 0.85$ across the study waves.

Problem behavior/delinquency. The measure of problem behavior was based on Farrell et al.'s Problem Behavior Frequency Scale (Farrell, King, White, & Valois, 2000). Fifteen items measuring the frequency of certain problem behaviors during the past 3 months

were combined and averaged into a single index representing general problem behavior. Respondents were asked how many times (0, 1–2, 3–5, 6–9, or 10 times or more) in the past 3 months they had skipped school, damaged school or other property, cheated on a test, been in a fight where someone was hit, threatened a teacher, threatened someone with a weapon, spread a false rumor about someone, started a fight between other people, drove a car when drinking, gone to school but skipped classes, excluded someone from their group of friends, picked on someone, hit someone they were dating, threatened to hurt someone they were dating, and hit or slapped another kid. The items were recoded to the median of each frequency range (e.g., 1–2 was recoded to 1.5; 6–9 was recoded to 7.5) and were summed and averaged. Possible scores ranged from 0 to 10. Scale reliability (Cronbach's alpha) for these measures ranged from $\alpha = 0.78$ at Wave 1 to $\alpha = 0.92$ at Wave 5, suggesting a reliable scale.

4.5.2.2 Perceived Peer Drug Use Behavior and Attitudes

Respondents were asked to indicate how many of their five closest friends they think drink alcohol, smoke cigarettes, use other kinds of tobacco, smoke marijuana, or use other drugs (cocaine, LSD, heroin, Ecstasy, or other). Response options were "none," "one," "a few," and "most or all." These items were summed to create a general measure of "friends' drug use." Scale reliability for this measure ranged from $\alpha = 0.81$ to $\alpha = 0.87$ across the study waves.

To assess perceived peer attitudes about drug use, respondents were asked to report how they think their friends would feel if they (the respondent) (a) used alcohol, (b) got drunk, (c) smoked cigarettes, (d) used other kinds of tobacco, (e) smoked marijuana, or (f) used other drugs. Response options were "like it a lot," "like it some," "dislike it some,"

or “dislike it a lot.” These items were summed to create a general measure of “friends’ tolerance of drug use.” This measure was highly reliable, with Cronbach’s alpha scores ranging from $\alpha = 0.90$ to $\alpha = 0.93$ across the study waves.

A descriptive norm measure of the perceived frequency of use of alcohol, cigarettes, other tobacco, inhalants, marijuana, and other hard drugs at the respondent’s school was included. Response options were “almost none,” “about one-quarter (25%),” “about half (50%),” “about three-quarters (75%),” and “almost all.” These items were combined into a single measure reflecting the perceived frequency of drug use at the school. Scale reliability for this measure ranged from $\alpha = 0.88$ to $\alpha = 0.90$ across the study waves.

4.5.2.3 Perceived Availability of Drugs

Respondents were asked to indicate how easy or hard it would be for them to get alcohol, cigarettes, other kinds of tobacco, inhalants, marijuana, and/or other drugs. Response options were “very hard,” “somewhat hard,” “somewhat easy,” and “very easy.” Responses for each of the six drugs were combined into a single measure of perceived general availability of drugs. Scale reliability for this measure across the study waves ranged from $\alpha = 0.88$ to $\alpha = 0.90$.

4.5.2.4 Social Conformity

Social values is an averaged scale measure of responses to three items. Respondents were asked to indicate how strongly they agree or disagree (5-point Likert scale) with the following statements: (a) “It is good to be honest,” (b) “People should not cheat on tests,” and (c) “In general, police deserve respect.” Response options ranged from “strongly agree” to “strongly disagree” (5-point Likert scale). Scale reliability was modest, ranging from 0.70 to 0.73 across study waves.

Religiosity is the sum of two items. Respondents were asked to indicate "How important is religion to you?" ("Not at all important" to "Very important," 4-point scale) and "How much do your religious beliefs influence what you do?" ("Not at all" to "Very much"). The scale reliability for these two items ranged from 0.72 to 0.81.

4.5.2.5 Academic Achievement, School Attachment, and Academic Aspirations

Academic achievement was measured with a grade point average score calculated as the average grade in each of four subjects: English/language arts, mathematics, history/social studies, and science. *School attachment,* developed by Battistich and Hom (1997), is an averaged scale made up of three items: (a) students in this school treat each other with respect, (b) students at this school are willing to go out of their way to help someone, and (c) my school is like a family. Scale reliability ranged from 0.80 to 0.87 across the study waves. *Academic aspirations* reflects the sum of two items asking the respondent to indicate how important or unimportant (a) finishing high school and (b) going to college are to them. Response options ranged from "very important" to "not at all important." Scale reliability ranged from 0.64 to 0.76.

4.5.2.6 Parental Influence

Two measures of perceived *parental disapproval of drug use* (for the mother and the father) were available. The respondent was asked to indicate the degree to which the mother and/or the father would like or dislike it if the teen (a) drank alcohol, (b) smoked cigarettes, (c) used other forms of tobacco, or (d) used marijuana or other drugs. Responses for these four items were averaged for each parent ($\alpha = 0.85$ to $\alpha = 0.93$). However, because there were fewer missing cases for the mother variable, and because the correlation between the

mother and father variables was quite high (~.60), only the mother variable was included in these analyses.

4.6 Analytic Approach

4.6.1 A Testable Operationalization of the Gateway Hypothesis

Kandel and Jessor (2002) identified three interrelated propositions that summarize current knowledge about the gateway hypothesis. In general, they maintain that questions related to the gateway hypothesis can be evaluated on the basis of evidence for (1) sequencing, (2) association, and (3) causality.

The "sequencing" proposition refers to the notion that the use of drugs follows an ordered or hierarchical pattern. As described earlier, this proposition has strong empirical support, with multiple studies consistently finding that the substance use sequence starts with alcohol, then proceeds to cigarettes, then marijuana, and then illicit drugs such as cocaine or heroin (Hawkins et al., 2002; Kandel, 1975, 1988, 1998, 2002, 2003; Kandel & Yamaguchi, 1985, 1993, 1999, 2002; Yamaguchi & Kandel, 1984a, 1984b, 1996; Chen & Kandel, 1995; Kandel et al., 1992; Kandel & Logan, 1984; Adler & Kandel, 1981; Kandel & Faust, 1975).

The "association" proposition of the gateway hypothesis is that the use of some drugs is associated with a statistically significant increased risk for more advanced drug use. As with the sequencing proposition, there appears to be strong support for this proposition (e.g., Hansen & Graham, 1991; Wagner & Anthony, 2002; Yu & Williford, 1992; Merrill, Kleber, Shwartz, Liu, & Lewis, 1999; Lessem et al., 2006; Wagner & Anthony, 2002; Miller & Volk, 1996; Pentz & Li, 2002; Botvin et al., 2000, 2002; Scheier et al., 2001).

The final proposition, "causality," suggests that the use of a gateway drug causes the later use of other drugs. As described earlier, given the significant practical barriers to

conducting causality studies with humans, the lack of evidence supporting this proposition is not surprising.

To facilitate the testing of potential gateway relationships between substances, Maldonado-Molina (2005) proposed an operational definition of the gateway hypothesis that combines the first two propositions of the gateway hypothesis—sequencing and association (Kandel & Jessor, 2002)—with a methodological operationalization of the gateway hypothesis proposed by Collins (2002), who suggests that there is a gateway relationship between two drugs if (1) there is a clear temporality whereby the use of one drug precedes the use of the other drug, and (2) the probability of using one drug is significantly greater for someone who has first used the other drug than for someone who has not. According to Collins (2002), both of these conditions are necessary for a gateway relationship between drugs to exist.

The operational definition of the gateway hypothesis proposed by Maldonado-Molina (2005) includes two possible gateway relationships: (1) a complete gateway relationship and (2) a partial gateway relationship. A complete gateway relationship between two drugs is indicated if the use of one drug (e.g., alcohol) precedes *and* increases the risk for the use of another drug (e.g., marijuana). A partial gateway relationship is indicated if one drug (e.g., alcohol) does not necessarily or always precede the use of another drug (e.g., marijuana) but significantly increases the likelihood of using the latter drug once used.

For example, a 2003 study (Tullis, Dupont, Frost-Pineda, & Gold, 2003) suggested that among a college student sample, marijuana use often precedes the use of tobacco, leading the authors to suggest that marijuana may in fact be a gateway to tobacco use, rather than the other way around. Although marijuana may in fact be a gateway to tobacco in some

populations, it is also plausible that, while not always preceding marijuana use, the use of tobacco increases the risk of marijuana use. The order of sequence is an important but not sufficient condition for a gateway relationship between two drugs. A drug that does not universally precede another may still be a partial gateway if it increases the risk of later drug use. Given that inhalants are not widely used, it is unlikely that the use of inhalants will precede the use of other drugs for a majority of adolescents. However, it is conceivable that inhalant use will significantly increase the risk for later drug use for that subgroup of adolescents who use inhalants first, suggesting a potential partial gateway relationship between inhalants and other drugs.

A series of probabilities can be empirically tested for each definitional component proposed by Maldonado-Molina (2005). Consider, for example, the potential relationship between inhalants and marijuana, in which inhalant use is posited to be a gateway to marijuana use. For a *complete* gateway relationship between these two drugs to exist, the probability of trying marijuana at Time 2, conditional on *not* having tried inhalants at Time 1, equals zero; in other words, everyone who tries marijuana at Time 2 had tried inhalants at Time 1. Additionally, the probability of trying marijuana at Time 2, conditional on having tried inhalants at Time 1, would be greater than zero, suggesting that inhalant use at Time 1 has increased the probability of marijuana use at Time 2 (Maldonado-Molina, 2005).

A *partial* gateway relationship between inhalants and marijuana exists if, even if inhalant use does not universally precede marijuana, the risk for marijuana use is increased once inhalants are used. Furthermore, evidence of a partial gateway relationship where inhalants serve as a gateway for marijuana use requires that having tried marijuana is not associated with an increased risk of inhalant use (Maldonado-Molina, 2005).

4.7 Latent Transition Analysis

LTA (Collins, 2002b; Velicer, Martin, & Collins, 1996; Collins et al., 1994; Collins & Wugalter, 1992; Lanza et al., 2003) is an extension of latent class theory to longitudinal data. In latent class theory, latent variables are categorical, and individuals are sorted into mutually exclusive and exhaustive latent classes based on a set of categorical item responses, in a way that is similar to factor analysis for continuous variables. Latent class analysis identifies latent classes in data and estimates their prevalence, while simultaneously adjusting estimates for measurement error (Lanza et al., 2003).

LTA offers a means for conducting analyses to explore models of stage-sequential development over time. LTA allows for the estimation of prevalence of stages (e.g., stages of drug use) and the incidence of transitions from one discrete stage to another over time (Lanza et al., 2003). A comprehensive overview of LTA is provided by Lanza, Flaherty, and Collins (2003).

Although relatively new, LTA is an increasingly popular procedure for testing models of stage-sequential change. LTA has been used to test a wide range of stage-based models, including stages of smoking behavior based on the Transtheoretical (stages of change) model (Velicer et al., 1996; Martin, Velicer, & Fava, 1996), alcohol abuse and dependency (Guo, Collins, Hill, & Hawkins, 2000), children's drawing development (Humphreys & Janson, 2000), and sexual behaviors among injecting drug users (Posner, Collins, Longshore, & Anglin, 1996). The most common use of LTA to date has been to test stage-sequential models of substance use, often based on the gateway hypothesis (Lanza & Collins, 2006; Collins, 2002; Hyatt & Collins, 2000; Collins et al., 1997).

LTA models may include both a dynamic part and a static part (all LTA models by definition include a dynamic part). The dynamic part of the model refers to the movement

(transition) through the stage sequence over time. For this dissertation, the dynamic part of the model refers to transitions in substance use stages (usually called latent statuses in LTA). It is possible to also include a static part of the model that does not change over time and that can be thought of as an exogenous, categorical predictor (grouping variable) that divides the sample into two or more groups or classes.

This dissertation study does not include a static component. Rather, analyses are completed separately for four race/gender subgroups: white males, white females, African American males, and African American females. While it would be possible to include a static component representing these four groups, this approach would only allow for an examination of differences in stage prevalence and transition probabilities while assuming that one single stage model is appropriate for each group. However, it is possible that important differences in the number and types of stages exist for the different groups. The selected approach of analyzing the four groups separately allows for a direct assessment of the hypothesis that the stages and patterns of drug use sequencing differ by race and gender.

As a latent variable approach, LTA can treat both the static and dynamic parts of the model as latent (unobserved and theoretically infallible), using multiple categorical manifest (observed, fallible) items. The use of multiple indicators increases the reliability of the measures by estimating random measurement error and removing this error from subsequent analyses, in a way conceptually analogous to structural equation modeling, thus yielding more reliable parameter estimates.

4.7.1 Parameters Estimated in the LTA Model

A total of five sets of parameters are potentially estimated for LTA models. These include estimates of the probability of membership in a certain fixed (static) group (class), the probability of membership in each stage of substance use, the probability of transitioning

to a higher level of substance use at a later time given the individual's stage at the previous time, and the measurement quality of all manifest indicators of the latent classes and latent stages.

The first set of parameters represents the probability of membership in each category of a grouping variable (latent class). These parameters are referred to as γ (gamma). This parameter is not required to run an LTA; inclusion of it allows for group comparisons in stage membership and transition probabilities. Again, the models to be tested in this dissertation research do not include a gamma (latent class) component.

The probability of being in a certain stage of substance use is the second set of parameters estimated by LTA and is referred to as δ (delta). These parameters allow for hypothesis testing based on the relative risk ratio and the difference of proportions between the different latent classes (Lanza & Collins, 2002). It is possible to estimate the probability of membership in one stage (e.g., "no use") compared with the probability of membership in a later stage (e.g., the "alcohol and cigarettes" stage). For this study, these parameters provide prevalence estimates for each stage of substance use.

The third set of parameters estimated for this model are the τ (tau) parameters, which make up the transition probability matrix, reflecting the transition probabilities from one drug use stage to another, from one time to the next. In essence, the transition probability matrix illustrates the probability of transitioning to each stage of substance use at Time 2, given the stage of substance use at Time 1. These parameters are important for examining gateway relationships between drugs. For example, it is possible, using the transition probability matrix, to estimate the probability of using marijuana at a later stage conditional on having tried inhalants, but not marijuana, at the previous stage.

The fourth and fifth sets of parameters reflect the measurement of the latent variable model. An LTA with both a static (latent class/grouping variable) and a dynamic (latent transition) component produces two sets of estimates of measurement error. These parameters are referred to as ρ (rho). Parameters related to the probability of a given response to an item conditional on latent stage (i.e., drug use stage) and time are referred to as "big" ρ. Parameters representing the probability of a particular response to a particular item, conditional on latent class membership, are referred to as "little" ρ. Again, the models tested for this dissertation do not include a latent class component. Thus, three parameters are estimated for the current analyses: δ (delta), τ (tau), and ρ (rho). These parameters are listed and defined in Table 4.7.

Table 4.7 LTA Parameters Estimated for This Study

Symbol	Definition
δ (delta)	Estimate of the proportion of the population in each latent stage at each measurement occasion
τ (tau)	The probability of being in a particular latent stage at Time 2, conditional on latent stage membership at Time 1
ρ (rho)	The probability of a particular item response, conditional on latent stage membership

These parameters are conceptually similar to factor loadings in factor analytic models and are used to determine which stages reflect a high probability of using each drug, allowing for interpretation of each substance use stage in the model. Constraints on the ρ parameters can be modeled to ensure measurement invariance over time or across groups.

4.7.2 Model Identification and Constraints in LTA Models

In order for a model to be estimated, it must be "identified," meaning at a minimum there is enough information in the data (Lix, Algina, & Keselman, 2003) to produce the number of parameter estimates specified in the model. Issues of under-identification can be

addressed by fixing or constraining certain parameters. No estimation is needed for a parameter fixed to a specified value, and parameters constrained to be equal require the estimation of only one parameter (Hyatt & Collins, 2000). Fixing or constraining certain parameters can also serve to specify and test nested models (for instance, one could compare a model where a transition from alcohol use to marijuana use is estimated freely versus a model where this transition is set to zero).

Parameter constraints are most often placed on the τ (tau) and ρ (rho) components (Collins, Lanza, Schafer, & Flaherty, 2002). Constraints on the τ parameters allow a specified model of change to be tested over time. For instance, a drug use onset model suggests that movement from one latent drug use stage to another is unidirectional. It would be illogical for someone who has indicated having ever used a substance at one time point to later indicate having never used the same substance, although this form of recanting does occur frequently in longitudinal adolescent drug use surveys (Fendrich, 2005; Fendrich & Rosenbaum, 2003; Golub & Johnson, 2001; Kandel et al., 1992). When fixing the transition matrix so that all illogical transitions are set to zero (not estimated), all illogical transitions are treated as measurement error, resulting in more stable and reliable estimates.

It is generally recommended that the ρ parameters (measurement parameters) for the latent transition model be constrained as equal across time points ensuring that the latent stages have the same meaning and are therefore more easily interpreted (Collins et al., 2002). The ρ's can also be constrained so that only two (for dichotomous measures) ρ parameters are estimated for each item: one for the probability of responding "yes" when a "yes" is expected and one for the probability of responding "no" when a "no" is expected (Hyatt &

Collins, 2000). This latter constraint greatly reduces the number of parameters being estimated, thus increasing the likelihood that the model will be identified.

4.7.3 Model Fit

LTA produces model fit indices by comparing the response pattern proportions predicted by the model with the actual response patterns present in the data. LTA produces a goodness-of-fit statistic called G^2, which expresses the degree of agreement between the predicted and observed proportions (Lanza & Collins, 2002). In theory, the G^2 is distributed as chi-square, but for most LTA models this is not the case, and the distribution of G^2 for these models is not known. A rough rule of thumb for assessing model fit is that if the value of the G^2 is substantially less than the degrees of freedom, there is evidence that the model fits the data reasonably well (Hyatt & Collins, 2000). WinLTA produces a goodness-of-fit G^2 that is adjusted for missing data (Collins et al., 2002). This fit statistic allows for the direct comparison of nested models (Hyatt & Collins, 2000).

In the case of non-nested model comparisons, as is the case when comparing models with a different number of latent stages (i.e., five stages versus six stages), it is necessary to assess relative model fit by identifying which of several competing models is optimal in terms of balancing fit and parsimony. Two penalized-likelihood criteria, the Akaike information criterion (AIC) and the Bayesian information criterion (BIC), can be used to assess relative fit for LTA models. Lower values on these criteria suggest a more optimal fit.

4.8 Using Latent Transition Analysis to Address the Research Questions

4.8.1 Research Question 1: Can the Gateway Hypothesis be Extended to Include Inhalants for African American and White, Male and Female Adolescents in Grades 6 through 8?

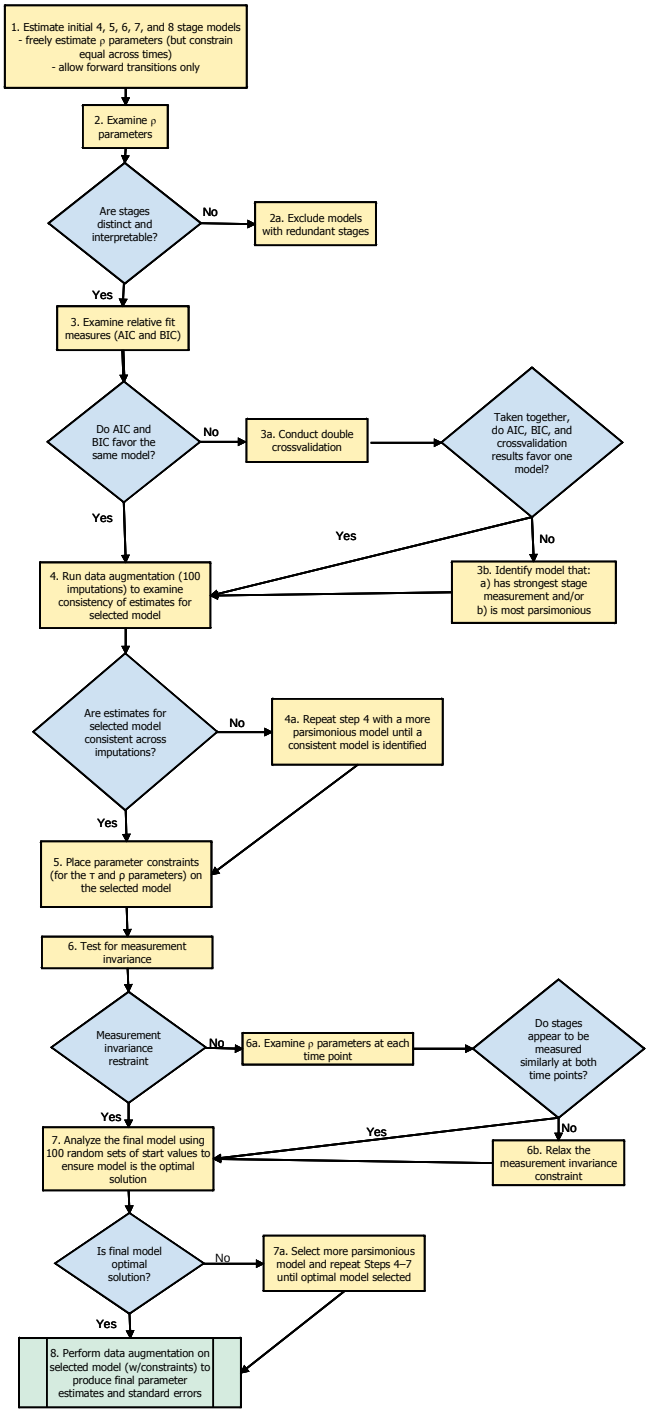
LTA provides a means for analyzing complex contingency tables for longitudinal data, and it is uniquely suited to testing models of stage-sequential change in drug use such as that proposed by the gateway hypothesis (Collins, 2002). Empirical model selection in LTA involves several steps, aimed at identifying a model that is both a parsimonious and an adequate representation of the data. Although the traditional representation of the gateway hypothesis provides some guidance, little is known about how inhalants may operate in gateway drug use sequencing. This is therefore an exploratory (versus confirmatory) LTA. The steps taken to conduct an LTA in order to address Research Question 1 are described below and illustrated in a flowchart in Figure 4.4.

4.8.1.1 Model Selection

An initial step in LTA involves fitting a series of models with different numbers of latent stages (latent statuses). In LTA, a latent categorical variable (i.e., drug use) is measured by a series of categorical manifest variables. Four separate manifest variables, one for each substance, have been dichotomized to represent the ever or never use of each substance. In this case, there are a total of 16 (2^4) possible unique stages of substance use.

In this study, model estimation began with a four-stage model. Five-, six-, and seven-stage models were subsequently estimated; for each of the four samples, models with eight or more stages either did not converge or included redundant stages. For African American males, a three-stage model was also estimated for the 6th–7th grade period, due to poor fit for the other models.

Figure 4.4 Model Selection Process Flowchart



Initial parameter constraints. In these initial models, the measurement parameters (ρ, Rho parameters) were estimated freely but constrained to be equal across both time points. These parameters represent the probabilities of responding "yes" or "no" to a substance use measure, conditional on time and stage membership, and provide a means of distinguishing the stages present for the particular model. For instance, a stage characterized by a high probability of responding yes to the alcohol item and no to all other items would represent an alcohol-only stage.

For the purpose of this study, the ρ parameters were constrained to be equal across times. This approach assumes that the measurement of the latent variable remains stable over time (measurement invariance) ensuring that the meaning of the latent stage remains consistent and aiding in model interpretation.

An additional constraint applied to these baseline models involved the transition (τ, Tau) matrix. Because all of the models being tested involve drug use onset—a "one-time" event—the Tau matrix was constrained to estimate only forward movement from Time 1 to Time 2; no backward movement was allowed.

Delta (δ) parameters, which represent the unconditional probability of being in a latent stage at a given time of measurement, were freely estimated for all analyses. These parameters provide the estimated probability of being in the "alcohol + cigarettes" (AC) stage at Time 1, for instance.

Assessing model fit. Two penalized log-likelihood test statistics, the AIC and the BIC, were used to identify the best relative model fit among the estimated baseline models. In the event that these two estimates identify the same model, that model is selected. However, in this study, these two estimates rarely agreed.

Double cross-validation was conducted on each of two randomly split samples for each study group and was used as an additional step to identify models with the best relative fit. Double cross-validation (Collins, Graham, Long, & Hansen, 1994) is recommended as an alternate means for assessing model fit, particularly in cases where data are incomplete (missing) or where multiple alternative models are being tested (Collins, Lanza, Schafer, & Flaherty, 2002).

The following description of double cross-validation is provided by the Methodology Center at Penn State University (http://methcenter.psu.edu/index.php/component/content/348?task=view):

> *The process of crossvalidation involves splitting a sample into two (or more) subsamples, for example, Sample A and Sample B, and fitting a series of plausible models to each sample. Each model is fitted to Sample A (the calibration sample), the predicted response frequencies for each model are compared to the observed response frequencies in Sample B (the crossvalidation sample), and G^2 is computed. Then the reverse is done; each model is fitted to Sample B (now the calibration sample), the predicted response frequencies for this model are compared to the observed response frequencies in Sample A (now the crossvalidation sample), and another G^2 is computed. A model crossvalidates well if the G^2 is relatively small when the estimated model is applied to a crossvalidation sample. When a series of models is tested, the model or models that crossvalidate best are considered best-fitting.*

Checking for model misspecification. In an effort to determine how stable the estimates for the various baseline models were, data augmentation (DA) was employed. Essentially, DA is a type of multiple imputation where the latent stages are treated as missing

data and random parameters based on the posterior distribution given the observed data are created. DA produces a sequence of plausible sets of LTA parameter estimates based on the observed data. The uncertainty present in the data results in a series of data sets that each contain randomly different values for the LTA parameters. The degree to which these values differ from the observed data is reflected in standard errors that are created when combining the multiply imputed data sets.

The primary purpose of DA in LTA is to produce standard errors, which are not a byproduct of the expectation-maximization (EM) algorithm used in LTA. In most cases, 10 imputed data sets are sufficient for producing reliable estimates in LTA models. However, DA has also been used here to examine the consistency of the estimates for the baseline models. For each of the models, 100 imputations were run and the results combined. Final Rho estimates from these combined estimates were examined to determine whether the original latent stages remained across the 100 random data sets. In several instances in this study, after applying DA, the number and/or type of latent stages present changed, suggesting that the selected model was inconsistent and that a simpler model (fewer stages) may be preferable.

Another approach to diagnosing model misspecification is to examine model-based residuals. The residuals represent the difference between the observed and expected cell frequencies. A large residual for a particular response pattern can indicate that the model does not adequately measure the response pattern and may point to adjustments that can be made to improve model fit. However, although several large residual values were present for the selected models (not shown), the residuals were related to patterns that involved backward transitions (i.e., moving from ever use of a drug to never use of the same drug). It

is apparent that freeing the transition matrix to allow "backsliding" may improve the fit of the models, but that would be illogical for an onset model.

Final model selection. In addition to the measures of relative fit described above, two additional criteria for model selection were used. First, after identifying consistent models using DA, the strength of the Rho parameters was examined. In cases where the relative fit between the models was not clearly distinguished by the relative fit measures (BIC, AIC, and cross-validation G^2) , the strength of the freely estimated Rho parameters was assessed to determine how well the defined latent stages for each model are measured. Although there is a general preference to select more parsimonious models (fewer latent stages), if a more complex model has similar relative model fit plus stronger measurement qualities and more clearly defined latent stages, the more complex model should be selected. Second, similarly, a more complex model may be a closer approximation of the hypothesized model. Although the paucity of research and theory related specifically to the role of inhalants as a gateway drug mandates that this be an empirical study, the general gateway hypothesis suggests a potential gateway model, a hypothetical example of which is described in Chapter 3 and illustrated in Figure 3.2. If a clearly superior model was not identified based on the relative measures of model fit (AIC and BIC), a model with good overall and relative fit, strong measurement properties, and concordance with the hypothesized gateway model is selected as the final model.

Final parameter constraints. Once a final model was selected, additional constraints were used to improve the stability and identification of the model and to ensure that the model allowed only for logical transitions. For each selected model, the ρ (Rho) parameters were constrained so that one estimate for the probability of a "yes" and one estimate for the

probability of a "no" response to a drug use question was estimated. The measurement invariance constraint remains in place. These constraints greatly reduce the number of parameters being estimated, increasing the likelihood that the model will be identified. The τ (Tau) matrix continues to be constrained to allow only forward-moving transitions. In some cases, depending on the latent stages present in the selected model, certain forward transitions are also constrained. Specific model constraints are described for each subsample in Chapter 5 (Results).

Testing for measurement invariance. The models tested in these analyses all assume measurement invariance across time points. This is a common constraint made to ensure that the meaning of the latent stages is uniform across times and that changes in drug use sequencing represent actual changes in reported use, as opposed to changes in the meaning of the latent stages. To assess the extent to which measurement invariance holds, the model fit for the constrained model is compared to a model where measurement is free to vary between the time points. Because these two models are directly nested (the constrained model is a simplified version of the unconstrained model), the values of the G^2 for each model can be directly compared using a χ^2 difference test. If the difference is not significant, this supports the use of the more parsimonious model where measurement invariance is assumed.

Final model identification. As a final test to determine whether the model selected is the best representation of the observed data, the constrained model for each subsample was analyzed using 100 random sets of start values (Lanza, Flaherty, & Collins, 2003). This approach is recommended to explore the presence of multiple modes. Ideally, all 100 solutions would be identical, suggesting that the "global maximum of the likelihood" had

been maximized (Lanza, Flaherty, & Collins, 2003, p. 671). In no case for the current analyses was any solution identical for all 100 solutions. In this case, the frequency of the alternate solutions and the G^2 for the alternate models were examined to select the final model—the optimal solution has likely been identified if the majority of the models converge to that same solution and it has the smallest log-likelihood value among the solutions obtained using the different random starting values (Lanza, Flaherty, & Collins, 2003).

Obtaining final parameter estimates and standard errors. The WinLTA software used to run these analyses uses an EM algorithm to obtain maximum likelihood estimates for the parameters (Collins, Lanza, & Schafer, 2002). Standard errors are not a byproduct of the EM algorithm, precluding hypothesis testing. DA is a multiple imputation approach to missing data and has been shown to produce high-quality estimates and reliable standard errors (Schafer, 1997). After selecting a final LTA model, the EM maximum likelihood estimates were used as starting values for DA to multiply impute the latent variables. Results from these multiple imputed data sets were then combined to provide an overall estimate of the standard error for each parameter (Collins et al., 2002). Using this information, the probabilities of stage membership and transition probabilities can be directly compared. The DA estimates are reported as the final results for each model.

The preceding section has described in detail the steps that were taken in the current study to identify and estimate models that provide the best relative fit to the data, after accounting for measurement error. This model selection process is illustrated in Figure 4.4.

4.8.1.2 Using the LTA Results to Evaluate the Gateway Hypothesis

A primary aim of this dissertation is to examine whether gateway relationships exist between inhalants and the drugs most commonly referred to as gateway drugs: alcohol,

cigarettes, and marijuana. The operational definition of the gateway hypothesis that distinguishes complete and partial gateway relationships based on conditional probabilities (Maldonado-Molina, 2005) served as a model for these analyses.

The gateway hypothesis (Kandel & Jessor, 2002) suggests that it is significantly less likely that adolescents will progress to illicit drug use without first using one of the "legal" drugs. This proposition has been tested almost exclusively with alcohol and tobacco, although Collins et al. (1997) demonstrated that the heavy use of caffeine, another legal substance, may increase the likelihood of drug use onset. To date, no study has tested the role inhalants may play in the "sequencing proposition" of the gateway hypothesis.

Using the results from the final selected LTA model, it is possible to test hypotheses about drug use sequencing, particularly the relationship between inhalants and the other gateway drugs. Certain drug use latent stages must be present in the data to facilitate testing of certain hypotheses. If for a final selected LTA model, inhalant use is only present as part of an "Alcohol + Cigarettes + Inhalants + Marijuana" (ACIM) stage, and not in a preceding stage, it will not be possible to test the hypothesis that inhalants serve a gateway role to marijuana use. The hypothesis that inhalants serve as a partial gateway to marijuana use would be rejected, and it would be concluded that inhalants do not serve any gateway function within this study population. If, however, the final model includes both an "Alcohol + Cigarettes + Marijuana" (ACM) stage and an "Alcohol + Cigarettes + Inhalants" (ACI) stage, the probability of transitioning from inhalants to marijuana, and from marijuana to inhalants, can be directly compared. Likewise, if the final model includes an "inhalants only" stage, the probability of transitioning from inhalants to alcohol and cigarettes can also be

tested and compared with the opposite transitions (e.g., alcohol to inhalants) to determine which probability is greater.

Using the definitions of complete and partial gateway relationships proposed by Maldonado-Molina (2005), it is possible to test what kind of gateway relationship exists between inhalants and the gateway drugs. To test for a complete gateway relationship for example, one estimates whether the probability of using alcohol, cigarettes, or marijuana at a later time, conditional on *not* having used inhalants at an earlier time, equals zero. The following three equations, adapted from Maldonado-Molina (2005, p. 17), provide as an example a test of the complete gateway relationship between inhalants and marijuana:

$P(\overline{inh}_t)>0$ Equation 1

$P(mar_{t'}|inh_t)>0$ Equation 2

$P(mar_{t'}|\overline{inh}_t) = 0$ Equation 3

where

$P(\overline{inh}_t)$ is the probability of *not* trying inhalants at an earlier time,

$P(mar_{t'}|inh_t)$ is the probability of trying marijuana at a later time conditional on having tried inhalants at an earlier time, and

$P(mar_{t'}|\overline{inh}_t)$ is the probability of trying marijuana at a later time conditional on *not* having tried inhalants at an earlier time.

Equation 3 is the most stringent condition for establishing a complete gateway relationship between two drugs. For instance, according to this sample equation, everyone who tries marijuana has tried inhalants first. It is presumed that, in any adolescent sample, a significant proportion of marijuana users have never used inhalants. For this reason, inhalants are better considered as a potential partial gateway to marijuana use.

A partial gateway relationship is assessed by estimating whether the probability of using marijuana, cigarettes, or alcohol after using inhalants is greater than the probability of using marijuana, cigarettes, or alcohol without having first used inhalants, while at the same time the probability of using inhalants after using marijuana, cigarettes, or alcohol is equal to or less than the probability of using inhalants without having first used marijuana, cigarettes, or alcohol (Maldonado-Molina, 2005). Extending the example of inhalant and marijuana use, the following equations (Maldonado-Molina, 2005, p. 18) provide a test of a partial gateway relationship:

$$P(mar_{t'}|inh_t) > P(mar_{t'}|\overline{inh_t}) \qquad \text{Equation 4}$$

$$P(inh_{t'}|mar_t) < P(inh_{t'}|\overline{mar_t}) \qquad \text{Equation 5}$$

where

$P(mar_{t'}|inh_t)$ is the probability of trying marijuana at a later time conditional on having tried inhalants at an earlier time,

$P(mar_{t'}|\overline{inh_t})$ is the probability of trying marijuana at a later time conditional on not having tried inhalants at an earlier time,

$P(inh_{t'}|mar_t)$ is the probability of trying inhalants at a later time conditional on having tried marijuana at an earlier time, and

$P(inh_{t'}|\overline{mar_t})$ is the probability of trying inhalants at a later time conditional on not having tried marijuana at an earlier time.

Based on these equations, there is support for a partial gateway relationship between inhalants and marijuana if having tried inhalants is associated with an increased risk of trying marijuana, but having tried marijuana is not associated with an increased risk of trying inhalants (Maldonado-Molina, 2005).

LTA provides a flexible approach to testing these equations (Maldonado-Molina, 2005). Consider, for example, a test of the complete gateway relationship definition for

inhalants and marijuana. Equation 1 states that the probability of not using inhalants at Time 1 is greater than zero. This probability can be assessed by summing the probability of membership in states that did not include the use of inhalants. Equation 2, which states that the probability of using marijuana at a later time conditional on having used inhalants at a previous time is greater than zero, is evaluated in LTA by estimating the proportion of adolescents who at Time 1 had used inhalants but not marijuana and who by a later time (t + 1) had initiated marijuana use.

The final condition of a complete gateway relationship between inhalants and marijuana (Equation 3) states that the probability of using marijuana at a later time (t + 1) conditional on not having used inhalants at an earlier time (t) equals zero. Testing this equation requires estimating the probability of stage membership in a stage that includes marijuana at a later time (t + 1) conditional on the probability of membership in stages with no inhalant use at Time 1. This estimate is calculated by adding the products of the conditional probabilities of using marijuana at the later time (t + 1) given that inhalants have not been used at Time 1 (t) and the probability of stage membership in each substance use stage at Time 1 and dividing this product by the probability of not having used inhalants (Maldonado-Molina, 2005).

Again, because inhalant use is not nearly as prevalent as alcohol or cigarette use, it is very unlikely that it will operate as a complete gateway to any substance, except perhaps for a small subgroup of adolescents. It is hypothesized, however, that inhalants may serve as a partial gateway to marijuana use because inhalants, while not always preceding marijuana use, may significantly increase the risk for later marijuana use.

The first condition supporting a partial gateway relationship is that the probability of using marijuana at Time 2 conditional on using inhalants at Time 1 is greater than the probability of using marijuana at Time 2 conditional on not having used inhalants at Time 1 (Maldonado-Molina, 2005). This condition compares the probability estimates from Equations 2 and 3. Specifically, this condition is tested by calculating the difference between the two probabilities: the probability of using marijuana at Time 2 conditional on using inhalants at Time 1 minus the probability of using marijuana at Time 2 conditional on not having used inhalants at Time 1 (Maldonado-Molina, 2005). If this difference is significantly greater than zero, there is evidence in support of this condition.

The final equation, and condition for a partial gateway relationship, is that the probability of using inhalants at a later time (t + 1) conditional on having used marijuana at an earlier time (t) is less than or equal to the probability of using inhalants at a later time (t + 1) conditional on not having used marijuana at an earlier time (t) (Maldonado-Molina, 2005). To calculate the probability of using inhalants at a later time conditional on first using marijuana, one estimates the probability of membership in any stage that included inhalants at the later time (t + 1) conditional on membership in any stage with marijuana at Time 1.

To satisfy the Equation 5 condition, the resultant probability of using inhalants at a later time conditional on the earlier use of marijuana needs to be less than or equal to the probability of using inhalants at a later time (t + 1) conditional on not having used marijuana at an earlier time (suggesting that the use of marijuana at Time 1 does not increase the probability of using inhalants at Time 2). This second part of the equation is estimated by calculating the probability of membership in a stage that includes inhalants at a later time

(t + 1) conditional on each stage that does not include marijuana at Time 1 (Maldonado-Molina, 2005).

4.8.2 Research Question 2: Does the Probability of Transitioning from Inhalant Use to Other Drug Use Remain after Controlling for Demographic Factors and Key Psychosocial Predictors of Adolescent Drug Use?

Software for conducting LTA with covariates has been released recently as a beta version (version 1.1.5) in SAS®. In addition to the typical LTA parameters previously described, an LTA with covariates includes up to two additional sets of beta (β) parameters: a set representing logistic regression coefficients for the covariates predicting baseline stage membership and a set representing logistic regression coefficients for covariates predicting transitions over time.

The purpose of this analysis was to determine whether the probability of transitioning from inhalant use to other drug use remains after controlling for other factors related to adolescent substance use. Therefore, this analysis at a minimum requires a transition model where a transition from inhalants to another drug use stage is present. The final models selected for each of the four samples (i.e., white males, white females, African American males, and African American females) and for both time points (6th to 7th grade and 7th to 8th grade) determine whether Research Question 2 can be assessed: there must be evidence for a gateway relationship (in analysis 1) to facilitate analysis 2. In this study, the results (Chapter 5) indicate that this relationship exists only for white females (at both transition periods). Therefore, analysis 2 is focused solely on the white female samples.

The final model selected for white females was extended to include covariates (Lanza & Collins, 2008). In an LTA-with-covariates, covariates are incorporated in the latent transition model using a logistic link function, and one or more covariates can be specified as covariates of (a) latent stage membership at Time 1(δ) and (b) transition probabilities from

Time 1 to Time 2. This results in two additional sets of β (beta) parameter estimates, which are logistic regression coefficients.

When covariates are included, the δ and τ parameters are calculated as functions of the β parameters and the covariates. This feature allows for a direct analysis of Research Question 2. Recall that the transition probability τ for a standard LTA without covariates is interpreted as *the probability of being in latent stage B at Time 2, given membership in latent stage A at Time 1.* When one or more covariates are included, the τ estimate is conditional on both Time 1 stage and the effect of the covariate(s). The interpretation of τ in this case is *the probability of being in latent stage B at Time 2, given membership in latent stage A at Time 1 and the value of the covariate(s).* It is therefore possible to assess the effect of the covariate on transition probabilities by comparing the parameter estimates from the basic LTA model with the estimates from the LTA-with-covariates model. If, after adding covariates to the model, a transition probability decreases substantially or disappears completely, this would be evidence that observed transition probability is more a function of the covariate than membership in the previous stage at Time 1.

This analysis focused specifically on the transition from inhalant use to other drug use. As mentioned, only white females included latent stages necessary to test the gateway hypothesis. Described in detail in Chapter 5 (Results), the LTA model for white females includes an "Alcohol + Cigarettes + Inhalants" (ACI) stage and an "Alcohol + Cigarettes + Inhalants + Marijuana" (ACIM) stage. It is therefore possible to assess the effects of covariates on the transition probability from the ACI stage to the ACIM stage as a direct test of the hypothesis that inhalant use acts as a partial gateway to marijuana use.

A number of psychosocial variables (e.g., perceived peer drug use, perceived drug availability, sensation seeking and delinquency, academic aspirations, and parental [mother's] disapproval of drug use) thought to represent common liabilities to drug use were included as covariates. Age was also included to account for possible heterogeneity of ages at each grade. The variables were first entered independently (bivariate analysis) to assess the independent effects.

The bivariate analyses were followed with a series of multivariate analyses. Variables that were statistically significant ($p < .05$) and were associated with a decrease in the size of the transition probability were retained. The purpose of this analysis was to determine whether a combination of covariates that fully or mostly account for the probability of transitioning from the ACI stage to the ACIM stage could be identified. Covariates were ranked in order of their independent effect on the transition probability and a series of increasingly large models were estimated. The first model included just the one variable with the strongest effect on the transition probability. Subsequent models added one covariate at a time in order of the size of their effect on the transition probability. A finding that the transition probability remains significant after controlling for competing factors would be evidence of a unique gateway relationship between inhalants and marijuana.

A review of the covariates indicated that the majority are heavily skewed (zero-inflated) and this coupled with the sparseness of the contingency table being estimated prevented estimation in some cases (models failed to converge) and made interpretation of the results difficult. Dichotomizing the variables (based on a median or mean split) improved estimation and made interpretation clearer ("age" remains continuous). Details of the recoded covariates are presented in Chapter 5 (Results).

4.8.3 LTA Software

The analyses were conducted using WinLTA (Collins et al., 2002), a free downloadable software designed to conduct latent class analysis (PROC LTA, 2007) and LTA. WinLTA handles missing data with a full-information maximum likelihood technique whereby the EM algorithm uses information from the model and incomplete data to estimate parameters iteratively (Hyatt & Collins, 2000).

WinLTA is an extremely flexible and user-friendly software program that is especially well-suited for model testing and model comparisons. This relates in part to the flexibility of adding or removing specific model constraints. For instance, in the drug use onset model, the use of constraints specifies a model where only forward transitions are allowed.

WinLTA does not include a feature to include covariates. A recently released beta version of an LTA procedure in SAS® (PROC LTA, beta version 1.1.5., 2007) allows for the estimation of LTA models with covariates. Separate sets of covariates can be specified for baseline and for each transition (e.g., Time 1 to Time 2). As in WinLTA, parameters are estimated by maximum likelihood using the EM algorithm, which allows for the estimation of models with missing data. Unlike WinLTA, SAS PROC LTA does not include a DA option; standard errors are not produced. Additionally, while the EM algorithim allows for missing data on the latent stage indicators, missing data on covariates are not allowed; any individual with missing data on a covariate included in the model was eliminated from the analysis (listwise deletion); this limitation may bias results for this study, as the percentage of cases dropped ranged from 4% for the 6th–7th grade transition to 11% for the 7th–8th grade transition.

CHAPTER 5

RESULTS

5.1 Research Question 1: Can the Gateway Hypothesis be Extended to Include Inhalants for African American and White, Male and Female Adolescents in Grades 6 through 8?

5.1.1 Model Selection and Description

The goodness-of-fit for latent transition analysis (LTA) models is assessed by comparing the response pattern frequencies predicted by the model with the response pattern frequencies observed in the data. The likelihood ratio statistic, G^2, expresses the degree of agreement between the predicted and observed response pattern frequencies. For this study, four dichotomous variables representing reported ever use of alcohol, cigarettes, inhalants, or marijuana were measured at two time points. Therefore, a total of 256 (2^{4*2}) unique response patterns are possible.

Reviewing the number of observed response patterns gives some indication of the degree of heterogeneity present within the samples. A small number relative to the sample size suggests that there is general similarity in the patterns of reported drug use for that sample; conversely, a large relative number of response patterns suggests variability in reported drug use and may signal a challenge to identifying a parsimonious model that adequately summarizes the observed response patterns.

Tables 5.1 and 5.2 list the number of unique observed response patterns for each of the four subsamples for the 6th–7th grade and 7th–8th grade transition periods. A high relative number in the second column, “number of response patterns,” suggests greater

heterogeneity. By dividing the sample size by the number of response patterns, an estimate of the number of individuals within a sample who share the same response pattern is obtained (the fourth column in Tables 5.1 and 5.2). This number, found in the fourth column ("number of individuals sharing the same response pattern"), is an estimate of the number of individuals who share the same response pattern—thus, it is a measure of homogeneity, where high relative numbers indicate greater homogeneity.

Table 5.1 Number of Unique Observed Response Patterns for Ever Use of Four Drugs, 6th–7th Grade

Sample	Number of Response Patterns	Sample Size	Number of Individuals Sharing the Same Response Pattern
White males	78	464	5.9
White females	68	464	6.8
African American males	116	363	3.1
African American females	79	339	4.3

Table 5.2 Number of Unique Observed Response Patterns for Ever Use of Four Drugs, 7th–8th Grade

Sample	Number of Response Patterns	Sample Size	Number of Individuals Sharing the Same Response Pattern
White males	123	955	7.8
White females	96	954	9.9
African American males	143	703	4.9
African American females	130	732	5.6

For the 6th–7th and 7th–8th grade samples, white females have relatively fewer unique response patterns, suggesting greater homogeneity of responses. African American males and females exhibit more variability in their response patterns than do white respondents. The issue is most pronounced for the 6th–7th grade transition: only about three

(3.1) individuals share each of the observed response patterns that are present among African American males, whereas approximately 7 (6.8) white females share each unique response pattern found in that population. This finding provides additional support for the decision to conduct analyses separately for each group—there is clearly a great deal of variation between groups in terms of the number of drug use patterns reported. The results, including model selection and description, for each of the four subsamples are presented separately below.

5.1.2 White Males

5.1.2.1 6th–7th Grade Transition

Table 5.3 provides goodness-of-fit measures for various LTA models for white males transitioning from the 6th grade to the 7th grade. These estimates are for the general baseline models, with ρ (measurement) parameters that are freely estimated. The latent stage labels shown in Table 5.3 are based on the pattern of ρ parameters for each model.

Table 5.3 Goodness-of-Fit for Various Models, White Males, 6th–7th Grade

Model[a]	G^2 (df)	AIC	BIC	Cross-validation G^2_a	Cross-validation G^2_b
4 (N, A, AC, ACIM)	171.01 (230)	221.01	324.51	177.846	219.495
5 (N, A, AC, ACM, ACIM)	140.74 (221)	208.74	349.49	183.094	235.458
6 (N, A, C, AC, ACM, ACIM)	120.31 (212)	206.31	384.32	189.162	233.439
7 (N, A, C, I, AC, ACM, ACIM)	95.65 (205)	195.65	402.64	179.261	226.558

[a] Model labels are based on the ρ parameters for the model.

N = 464

Notes: A = alcohol; AC = alcohol + cigarettes; ACIM = alcohol + cigarettes + inhalants + marijuana; ACM = alcohol + cigarettes + marijuana; C = cigarettes; I = inhalants; N = no use.

As a general rule of thumb, G^2 values that are less than the degrees of freedom suggest a good overall fit. In this case, all of the models appear to fit the data well. The Akaike information criterion (AIC) and Bayesian information criterion (BIC) estimates are

inconsistent, designating different models as having the best model fit (lower scores indicate a better fit), in a pattern that is consistent across the other subsamples as well: AIC favors the most complex model (seven stages), whereas BIC favors the most parsimonious model (four stages). Cross-validation results, where lower G^2 values suggest a better relative fit, provide support for the four-stage model; the four-stage model cross-validates best for both random samples. The general principle of parsimony—when all else is equal, favor the most simple acceptable model—also supports the selection of the four-stage model.

Examining the strength of the measurement of the respective models is another step toward determining the best-fitting model. A more complex model may be desirable if the measurement of each latent stage is stronger than for a more parsimonious model. The ρ parameter estimates give an indication of the measurement for each stage. These parameters are similar to factor loadings in factor analysis, although they represent probabilities rather than loadings. Patterns of the ρ parameters are assessed to "label" the latent stages. Numbers close to one and close to zero suggest that membership in the latent stage is associated with a high probability of responding yes or no to the item. A probability of .50 suggests an equal probability of responding either yes or no, an indication of weak measurement. For the four-stage model, the probability of responding "yes" to each of the four drug use items, given membership in one of the four stages, is presented in Table 5.4. Again, the latent stage labels are based on the pattern of ρ estimates. Numbers close to "1" represent a high probability of responding "yes" to a drug-use item conditional on latent stage membership, whereas numbers close to "0" represent a low probability (and conversely a high probability of responding "no" to a drug use item), given latent stage membership.

Table 5.4 Freely Estimated ρ Parameters for Response "Yes," Four-Stage Model, White Males, 6th–7th Grade

	Latent Stage			
Item	**No Use**	**Alcohol**	**Alcohol + Cigarettes**	**Alcohol + Cigarettes + Inhalants + Marijuana**
Ever used alcohol	.02	**.91**	**.74**	**.97**
Ever used cigarettes	.02	.12	**.97**	**.96**
Ever used inhalants	.03	.11	.05	**.68**
Ever used marijuana	.00	.00	.12	**.71**

Note: ρ parameters are constrained equal for both time points, so the estimates are the same for both grades.

Similarly strong measurement of the latent stages was present for the five-, six-, and seven-stage models; no clear optimal model is identified. However, when each of these models was analyzed using data augmentation (DA) (with 100 imputations), additional support for the four-stage model emerged. The ρ (Rho) parameter estimates for the four-stage model suggest that the measurement of the four latent stages is consistent across imputations; that is, the same four stages are present, and the measurement quality is similar to that obtained in the original LTA. The more complex models were unstable across the imputed data sets. In fact, for each (five-, six-, and seven-latent stage) model, the same four stages present in the labeled four-stage model are the only ones that remain identifiable across the imputed data sets. Based on this collection of evidence, for white males transitioning from 6th to 7th grade, the four-stage model was selected as the final model. The stages represent "No use" (N), "Alcohol only" (A), "Alcohol + Cigarettes" (AC), and "Alcohol + Cigarettes + Inhalants + Marijuana" (ACIM).

Parameter constraints for the final model. To obtain final parameter estimates for the four-stage model and to ensure model identification, constraints were placed on the measurement (ρ) and transition (τ) matrices. The general pattern of constraints is similar for

each of the subsamples as is presented here as an example. Table 5.5 illustrates the constraints placed on the ρ parameters. The numbers listed in the table are arbitrary; for the WinLTA software, a "1" indicates that the parameter is freely estimated, and numbers greater than 1 can be used to create sets of equivalent estimates. Each "unique" number is freely estimated, whereas a single estimate is provided for cases where the same number is repeated. The matrix is constrained in order to estimate the probability of responding "yes" and the probability of responding "no" to a drug use item, conditional on latent stage membership. In this case, a total of 16 parameters are estimated, as opposed to a total possible number of 64 (32 x 2 time points) parameters.

Table 5.5 Constraints on ρ Parameters for White Males, 6th–7th Grade

		Drug Use Item			
	Latent Stage	**Ever Used Alcohol**	**Ever Used Cigarettes**	**Ever Used Inhalants**	**Ever Used Marijuana**
Probability of responding "no" given latent stage membership	No use	2	7	11	15
	A	5	7	11	15
	AC	5	9	11	15
	ACIM	5	9	13	17
Probability of responding "yes" given latent stage membership	No use	4	8	12	16
	A	6	8	12	16
	AC	6	10	12	16
	ACIM	6	10	14	18

Notes: A = alcohol; AC = alcohol + cigarettes; ACIM = alcohol + cigarettes + inhalants + marijuana; ACM = alcohol + cigarettes + marijuana.

Each unique number is freely estimated. Same numbers are constrained to be equal. For instance, the probability of responding "yes" to the alcohol ever use item given membership in the A, AC, or ACIM latent stage is constrained to be equal. This constraint ensures that the meaning of the alcohol use item is held constant across latent stages. Estimates are also constrained to be equal for both time points (measurement invariance).

The transition matrix (τ) (Table 5.6) reflects the fact that this is an onset (ever-use) model. In this case, an individual is free to progress to a "later" drug use stage, but they

cannot revert to an earlier stage (e.g., someone who reported ever using alcohol at Time 1 cannot be in the "no use" stage at Time 2). Based on the gateway hypothesis, it is assumed that, while an individual can transition from "no use" to one of the more advanced stages, the probability of transitioning will be greater for those who have tried alcohol or alcohol and cigarettes.

Table 5.6 Constraints on τ Parameters for White Males, 6th–7th Grade

	No Use	A	AC	ACIM
No use	FR	FR	FR	FR
A	0	FR	FR	FR
AC	0	0	FR	FR
ACIM	0	0	0	FR

Notes: A = alcohol only, AC = alcohol + cigarettes, ACIM = alcohol + cigarettes + inhalants + marijuana; FR = freely estimated; 0 = fixed to zero (not estimated).

To ensure that the final model, with the applied constraints, is the proper solution for the four-class model, the model was analyzed 100 separate times, using random start values. Two models emerged: the selected four-stage model and an alternate three-stage model (N + C + AC). The four-stage model was the most frequent solution: 63 of the 100 analyses supported the four-stage model. Additionally, the G^2 associated with the four-stage model (336.68) was substantially lower than the G^2 associated with the three-stage model (568.17).

The assumption of measurement invariance was tested via a χ^2 difference test for the difference between the model with the ρ parameters constrained to be equal (invariant) for both time points (G^2 = 194.315, 238 *df*) and the model without the measurement invariance constraint (G^2 = 186.110, 230 *df*). The difference of 8.205, with 8 degrees of freedom, is not significant (p = .4137), supporting the decision to constrain measurement across times.

Final model results, white males, 6th–7th grade. To obtain final parameter estimates and standard errors, DA was conducted. Whereas DA was used earlier to assess the

stability of the unconstrained model across 100 imputed data sets, here DA was applied to the final constrained model, and the results were combined to generate final parameter estimates that take into account the uncertainty present across the imputed data sets.

ρ parameters (model measurement). The final ρ parameter estimates, specifically the probability of responding "yes" to each item, along with 95% confidence intervals, are presented in Table 5.7. The values were constrained to be equal across time (measurement invariance), so the ρ parameters are the same for both time points. To achieve identification and model stability, additional constraints were imposed such that only two parameters were estimated for each item; the probability of responding "no" can be obtained by subtracting the parameters in Table 5.7 from 1.00.

Table 5.7 Final ρ Parameter Estimates and 95% Confidence Intervals for Response "Yes," Four-Stage Model, White Males, 6th–7th Grade

	Latent Stage			
Item	**No Use**	**Alcohol**	**Alcohol + Cigarettes**	**Alcohol + Cigarettes + Inhalants + Marijuana**
Ever used alcohol	.03 (.00, .13)	**.88 (.83, .92)**	**.88 (.83, .92)**	**.88 (.83, .92)**
Ever used cigarettes	.05 (.03, .10)	.05 (.03, .10)	**.93 (.87, .97)**	**.93 (.87, .97)**
Ever used inhalants	.06 (.04, .08)	.06 (.04, .08)	.06 (.04, .08)	**.59 (.50, .68)**
Ever used marijuana	.01 (.00, .02)	.01 (.00, .02)	.01 (.01, .02)	**.72 (.59, .82)**

Note: Point estimates and 95% confidence intervals based on data augmentation.

Most of the parameter estimates are near 0 and 1, indicating that the latent variable "substance use" is being measured accurately. For instance, the probability of responding "yes" to the alcohol item given membership in one of the three alcohol use stages is .88 (95% CI: .83, .92). The relatively weak measurement of the inhalant use item (and to a lesser extent

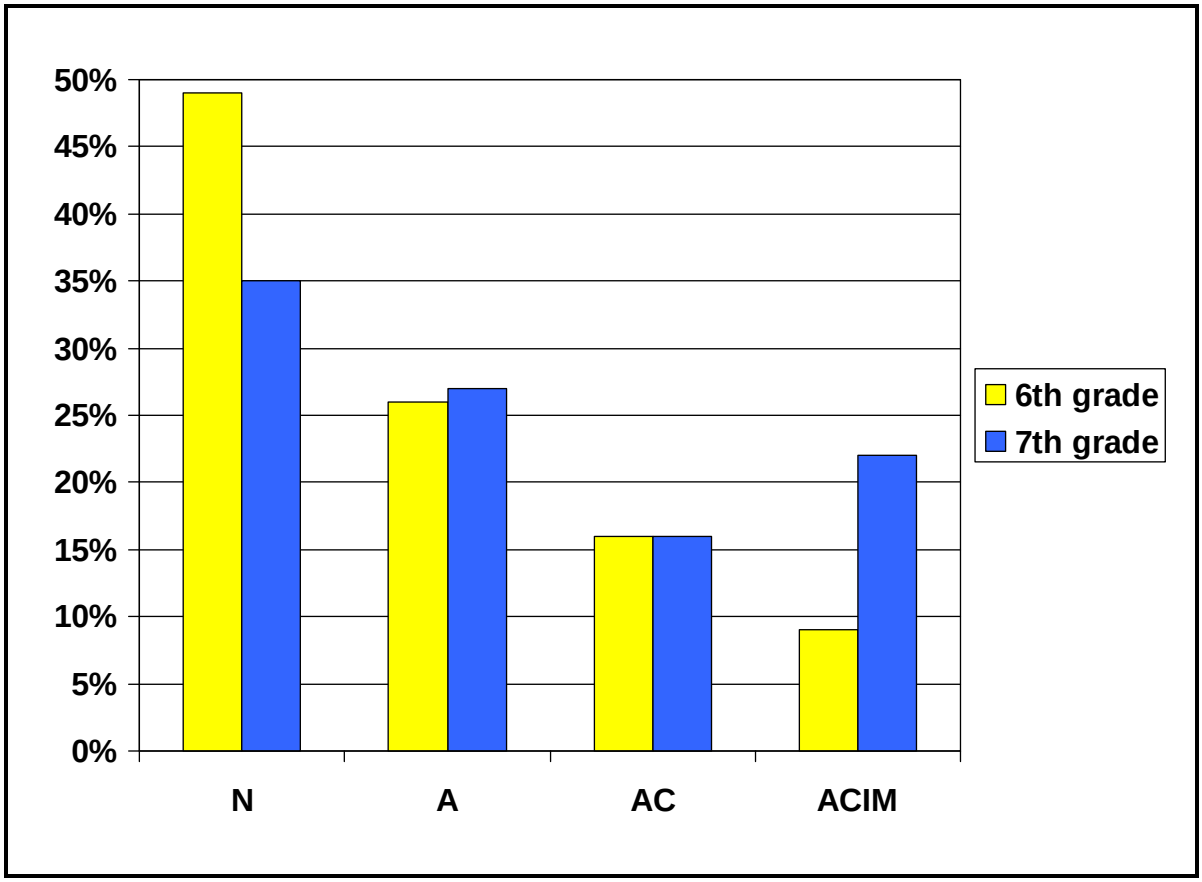
the marijuana item) should be noted. The estimated probability that a respondent will indicate having tried inhalants when he has not in fact tried them is only .06. But the estimated probability of a respondent indicating that they have not tried inhalants when according to their latent stage they are expected to have tried them is .41 (1.0 – .59), suggesting that the latent stage ACIM does a poor job predicting inhalant use. Membership in the ACIM latent stage is associated with a .59 (95% CI: .50, .68) probability of responding "yes" to the inhalant use item and a .72 (95% CI: .59, .82) probability for marijuana. The confidence interval for the inhalants measure includes .50, indicating that the probability is not significantly different from an equal probability of a "yes" or "no" response given latent stage membership.

δ parameters: probabilities of latent stage membership. δ parameters represent the probability of being in a certain latent stage. Table 5.8 and Figure 5.1 show the estimated proportion of adolescents in each of the four latent substance use stages in 6th and 7th grade.

Table 5.8 Final δ Parameter Estimates for Four-Stage Model, White Males, 6th–7th Grade

Latent Stage	6th Grade	7th Grade
No use	.49	.35
Alcohol	.26	.27
Alcohol + cigarettes	.16	.16
Alcohol + cigarettes + inhalants + marijuana	.09	.22

Figure 5.1 Overall Prevalence of Substance Use Stages, White Males, 6th–7th Grade



Note: N = no use; A = alcohol only; AC = alcohol + cigarettes; ACIM = alcohol + cigarettes + inhalants + marijuana.

In 6th grade, roughly half of the white males in the sample are expected to be in the "no use" latent stage, whereas one-quarter are expected to be in the alcohol-only stage. Prevalence rate estimates for each of the four substances can be calculated by combining across stages with common substance use items. For instance, the prevalence estimate for alcohol use in 6th grade is (.26 + .16 + .09) = .51, suggesting that more 6th grade white males have tried alcohol than are in the "no use" stage. The overall prevalence estimate for cigarettes is .25, while, based on this model, the prevalence of inhalant use and marijuana use is identical at .09. However, as noted above, these results should be interpreted with caution given the relatively poor measurement of inhalant use.

δ estimates for grade 7 indicate that the number of 7th grade white males expected to be in the "no use" stage has decreased substantially from grade 6, whereas the number in the ACIM stage increased from 9% to 22%. The estimates for the "alcohol" and the "alcohol + cigarettes" stages are similar at both grades.

τ parameters: transition probabilities. The τ parameters express the probability of transitioning from one latent stage to another between grade 6 and grade 7. The τ matrix is presented in Table 5.9.

Table 5.9 τ Parameter Estimates and 95% Confidence Intervals, White Males, 6th–7th Grade

	Latent Stage in 7th Grade				
Latent Stage in 6th Grade	**N**	**A**	**AC**	**ACIM**	**Advance Rate**
No use (N)	.717 (.63, .79)	.128 (.06, .23)	.090 (.05, .16)	.065 (.03, .13)	.283
Alcohol (A)	—	.775 (.65, .87)	.086 (.01, .31)	.139 (.07, .24)	.225
Alcohol + cigarettes (AC)	—	—	.564 (.39, .73)	.436 (.27, .61)	.436
Alcohol + cigarettes + inhalants + marijuana (ACIM)	—	—	—	1.0	
Overall advance rate					.267

Notes: The τ parameter estimates represent the probability of transitioning to the column "latent stage in 7th grade," conditional on membership in the row "latent stage in 6th grade."

Dash (—) indicates that parameter was fixed to zero to represent the onset model.

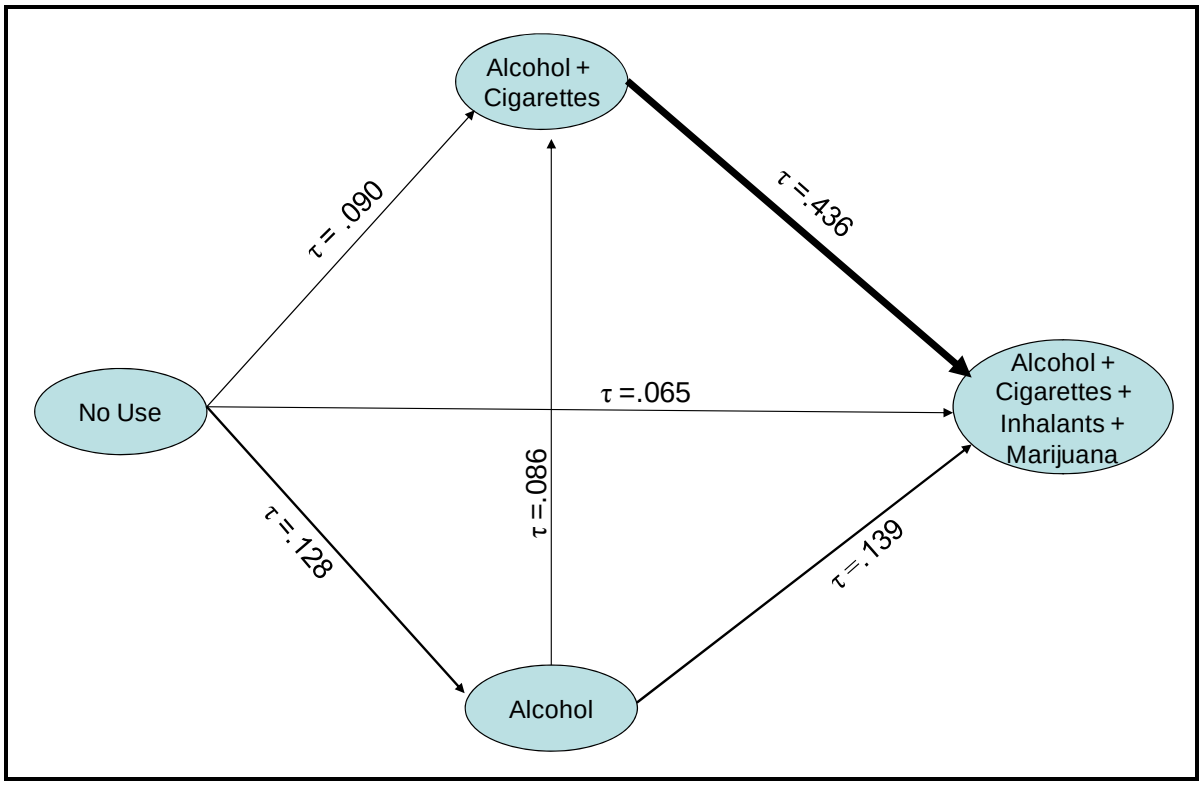
Point estimates and 95% confidence intervals based on data augmentation.

The probability of transitioning from the "no use" stage to one of the drug use stages is .283; roughly 72% of the non-users in 6th grade remained non-users in 7th grade. The largest probability for transition from the "no use" stage is to the alcohol stage, which is consistent with the generally reported gateway hypothesis, where alcohol is typically the first substance tried. The substantial probability (.065) of transitioning from "no use" directly to the most advanced stage (ACIM) is not predicted by the gateway hypothesis.

However, it is possible that the actual transition sequence from "no use" to ACIM is obscured by the year spacing used for this analysis. For instance, it is possible that an individual in the "no use" stage at 6th grade tried alcohol, then tried cigarettes, and then tried ACIM, all within the 1 year time frame, but those pathways would be obscured by the fact that assessments are for the 6th and 7th grades. Based on this model we might assume that inhalants and marijuana are tried so close together in time that we cannot tell which comes first, so they are essentially concurrent for this model. We know that alcohol is tried before cigarettes; nobody tried cigarettes without first trying alcohol (otherwise there would be a cigarettes-only [C] stage). We also know that cigarettes are tried before inhalants and marijuana, as evidenced by the AC stage and the fact that there is no AIM stage—no one used IM without having first used cigarettes. Therefore, the N to ACIM and the A to ACIM transitions should not be interpreted as representing the conditional probability of jumping directly from N or A to ACIM; rather, they should be interpreted as the conditional probability of proceeding from N to A to AC and then to ACIM.

Interestingly, the advance rate for alcohol-only users in 6th grade was lower than for non-users. Only 23% of these individuals transitioned to a more advanced stage. In contrast, nearly 44% of individuals in the AC stage transitioned to the ACIM stage. The combination of alcohol and cigarette use in this sample is clearly associated with a significant increase in the probability of transitioning to the most advanced stage in the model. Figure 5.2 presents the final transition model for white males transitioning from 6th to 7th grade.

Figure 5.2 Final Four-Stage Model for White Males, 6th–7th Grade, with Transitional Probability Estimates



Research Question 1 asks, "can the gateway hypothesis be extended to include inhalants for African American and white adolescents…?" These preliminary results suggest that the gateway model can be expanded to include inhalants for white males transitioning from 6th to 7th grade, as evidenced by the presence of the ACIM stage. Two of the study Hypotheses (1.1 and 1.2) for Research Question 1 can be examined here. Hypothesis 1.1 states that "inhalant use will precede marijuana use for a significant number of adolescents," whereas Hypothesis 1.2 suggests that inhalants will operate formally as a partial gateway to marijuana use. For this sample of white male adolescents transitioning from 6th to 7th grade, there is no evidence that inhalant use precedes, or is a gateway to, alcohol, cigarette, or marijuana use and therefore no evidence in support of these hypotheses.

The results suggest that marijuana and inhalants are rarely used without having also used the other; however, it is worth noting that all of the models except the four-stage model included a separate "alcohol + cigarettes + marijuana" (ACM) stage. The fact that these more complex models were not consistent or stable suggests that, although there is evidence that a separate stage (ACM) may exist in the study population, it is a rare stage, or that after accounting for measurement error, the current sample size may be insufficient to consistently detect it. Unlike previous studies of the gateway hypothesis, there is no evidence to suggest that a separate, cigarettes-only stage is warranted.

5.1.2.2 7th–8th Grade Transition

Table 5.10 provides goodness-of-fit measures for various LTA models for white males transitioning from 7th to 8th grade. Unlike the 6th–7th grade sample, all of the G^2 values are larger than the degrees of freedom, rough evidence that none of the models appear to fit the data especially well. Note that a seven-stage model was estimated, but a review of the ρ parameters suggested that two of the seven latent stages were redundant, so it was excluded. The stages present in the four-, five-, and six-stage model are the same as those identified for white males in the 6th–7th grade sample, which is evidence for the consistency of the models over time.

The AIC and BIC estimates designate different models as having the best model fit, with the AIC favoring the six-stage model and the BIC favoring the five-stage model. Cross-validation results are ambiguous; the six-stage model cross-validates best for one of the random samples and the five-stage model was the better fit for the other sample.

Table 5.10 Goodness-of-Fit for Various Models, White Males, 7th–8th Grade

Model	G^2 (df)	AIC	BIC	Cross-validation G^2_a	Cross-validation G^2_b
4 (N, A, AC, ACIM)	383.34 (230)	433.34	554.89	256.656	304.390
5 (N, A, AC, ACM, ACIM)	317.21 (221)	385.21	550.51	258.341	275.932
6 (N, A, C, AC, ACM, ACIM)	274.36 (212)	360.36	569.41	245.337	292.483

Notes: A = alcohol; AC = alcohol + cigarettes; ACIM = alcohol + cigarettes + inhalants + marijuana; ACM = alcohol + cigarettes + marijuana; N = no use.

N = 955.

Model labels are based on the ρ parameters for the model.

Seven-stage model included two redundant latent stages (only six unique latent stages).

The ρ parameters for each model were examined to determine how well the latent stages are measured. In these baseline models, measurement is unconstrained—the ρ parameters are freely estimated (although the parameter estimates are held constant for the two time periods). Initial LTA estimates (not shown) for the four-, five-, and six-stage models indicate strong measurement of the latent stages, although the four-stage model had one weak ρ estimate: the probability of responding "yes" to the inhalant use item conditional on membership in a latent stage that includes inhalant use was estimated at .53—barely larger than chance. The five- and six-stage models have stronger initial measurement properties.

For the five-stage model, the probability of responding "yes" to each of the four drug use items, given membership in one of the five stages, is presented in Table 5.11. The ρ parameters indicate overall strong measurement of five distinct stages. For instance, members of the "no use" stage have virtually zero probability of responding "yes" to any of the four drug use measures, as would be expected. Adolescents in the "alcohol + cigarette + marijuana" stage have very high probabilities of responding "yes" to the alcohol (.96), cigarette (.94), and marijuana (1.00) items.

Table 5.11 Freely Estimated ρ Parameters for Response "Yes," Five-Stage Model, White Males, 7th–8th Grade

	Latent Stage				
Item	**No Use**	**Alcohol**	**Alcohol + Cigarettes**	**Alcohol + Cigarettes + Marijuana**	**Alcohol + Cigarettes + Inhalants + Marijuana**
Ever used alcohol	.06	**.95**	**.81**	**.96**	**.89**
Ever used cigarettes	.02	.00	**.82**	**.94**	**.86**
Ever used inhalants	.02	.10	.03	.07	**.80**
Ever used marijuana	.00	.00	.05	**1.00**	**.63**

Note: Item-response probabilities (ρ parameters) are constrained equal for both time points, so the estimates are the same for both grades.

When each of these three models was analyzed using DA (with 100 imputations), the ρ (Rho) parameter estimates for the four- and five-stage models were consistent across imputations. However, the meaning of the latent stages changed for the six-stage model. Specifically, the single status for "cigarettes only" no longer existed, and only five distinct stages (the same identified in the original five-stage model) were interpretable, indicating that the six-stage model was unstable across the imputed data sets. Both the AIC and the BIC for the five-stage model suggest a better fit than for the four-stage model, and because the measurement for the five-stage model was good, it was selected as the final model for white males transitioning from 7th to 8th grade. The stages represent "no drug use" (N), "alcohol only" (A), "alcohol + cigarettes" (AC), "alcohol + cigarettes + marijuana" (ACM), and "alcohol + cigarettes + inhalants + marijuana" (ACIM).

Parameter constraints for the final model. To obtain final parameter estimates for the five-stage model and to ensure model identification, constraints were placed on the measurement (ρ) and transition (τ) matrices in the same way as for the 6th–7th grade model

(with the addition of one stage). Table 5.12 illustrates the constraints placed on the ρ parameters. Table 5.13 provides the parameter constraints for the τ matrix.

Table 5.12 Constraints on *ρ* Parameters for White Males, 7th–8th Grade

		Drug Use Item			
	Latent Stage	**Ever Tried Alcohol**	**Ever Tried Cigarettes**	**Ever Tried Inhalants**	**Ever Tried Marijuana**
Probability of responding "no" given latent stage membership	No use	2	7	11	15
	A	5	7	11	15
	AC	5	9	11	15
	ACM	5	9	11	17
	ACIM	5	9	13	17
Probability of responding "yes" given latent stage membership	No use	4	8	12	16
	A	6	8	12	16
	AC	6	10	12	16
	ACM	6	10	12	18
	ACIM	6	10	14	18

Notes: A = alcohol only, AC = alcohol + cigarettes, ACIM = alcohol + cigarettes + inhalants + marijuana.
Each unique number is freely estimated. Same numbers are constrained to be equal. For instance, the probability of responding "Yes" to the alcohol ever use item given membership in any of the A, AC, ACM, or ACIM latent stages is constrained to be equal. This constraint ensures that the meaning of the alcohol use item is held constant across latent stages. Estimates are also constrained to be equal for both time points (measurement invariance).

Table 5.13 Constraints on *τ* Parameters for White Males, 7th–8th Grade

	No Use	**A**	**AC**	**ACM**	**ACIM**
No use	FR	FR	FR	FR	FR
A	0	FR	FR	FR	FR
AC	0	0	FR	FR	FR
ACM	0	0	0	FR	FR
ACIM	0	0	0	0	FR

Notes: A = alcohol only, AC = alcohol + cigarettes, ACIM = alcohol + cigarettes + inhalants + marijuana; FR = freely estimated; 0 = fixed to zero (not estimated).

To ensure that the final model, with the applied constraints, is the proper solution for the five-stage model, the model was analyzed 100 separate times, using random start values. The originally identified five-stage model was the most frequently obtained result, with 56 out of 100 analyses producing the same result. It also had easily the lowest (best) G^2 of

584.85. Two alternate models also emerged, one with just three distinct stages that was obtained 43 times ($G^2 = 949.22$) and an alternate five-stage model that was obtained just once ($G^2 = 1471.82$).

The assumption of measurement invariance was tested via a χ^2 difference test for the difference between the model with the ρ parameters constrained to be equal (invariant) for both time points ($G^2 = 360.168$, 233 *df*) and the model without the measurement invariance constraint ($G^2 = 344.918$, 225 *df*). The difference of 15.25, with 8 degrees of freedom, is not significant ($p = .055$), supporting the decision to constrain measurement across times.

Final model results, white males, 7th-8th grade.

ρ parameters (model measurement). The final ρ parameter estimates and 95% confidence intervals for white males in the 7th–8th grade transition period are presented in Table 5.14. As with the model for the 6th–7th grade transition, the majority of ρ parameters are close to zero and one, suggesting good measurement. Inhalant use (.81) is more strongly measured in this model.

Table 5.14 Final ρ Parameter Estimates for Response "Yes," Five-Stage Model, White Males, 7th–8th Grade

	Latent Stage				
Item	**No Use**	**Alcohol**	**Alcohol + Cigarettes**	**Alcohol + Cigarettes+ Marijuana**	**Alcohol + Cigarettes + Inhalants + Marijuana**
Ever used alcohol	.03 (.01, .14)	**.87 (.85, .90)**	**.87 (.85, .90)**	**.87 (.85, .90)**	**.87 (.85, .90)**
Ever used cigarettes	.05 (.03, .08)	.05 (.03, .08)	**.87 (.84, .90)**	**.87 (.84, .90)**	**.87 (.84, .90)**
Ever used inhalants	.05 (.04, .07)	.05 (.04, .07)	.05 (.04, .07)	.05 (.04, .07)	**.81 (.71, .88)**
Ever used marijuana	.01 (.00, .01)	.01 (.00, .01)	.01 (.00, .01)	**.69 (.62, .74)**	**.69 (.62, .74)**

Note: Point estimates and 95% confidence intervals based on data augmentation.

δ parameters: probabilities of latent stage membership. Table 5.15 shows the estimated proportion of adolescents in each of the four latent substance use stages in 7th and

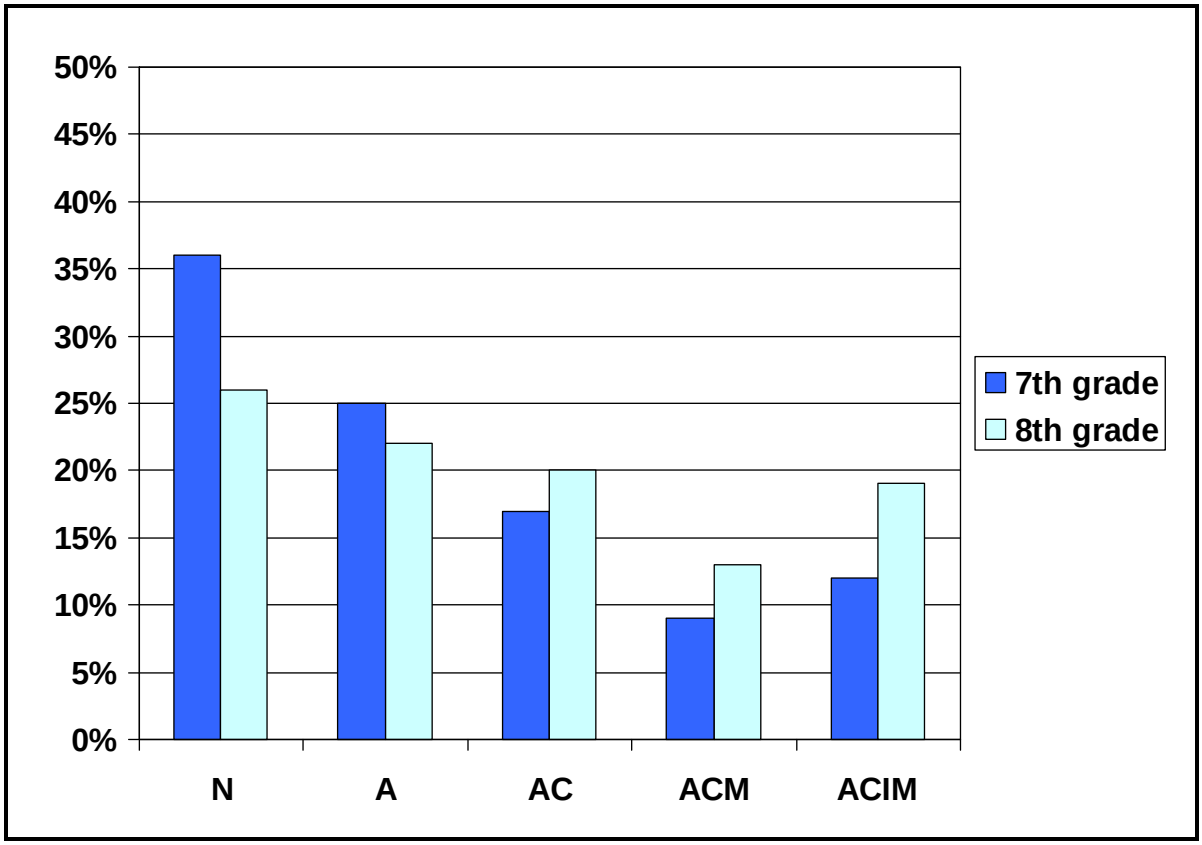
8th grades. The most common latent stage at 7th and 8th grades is the "no use" stage. However, prevalence of the "no use" stage decreases sharply from 7th to 8th grade, from 36% to 26%. By 8th grade, the ACIM stage (19%) is nearly as prevalent as the AC stage (20%). The prevalence of ever using alcohol is estimated to be (.25 + .17 + .09 + .12) = 63% in 7th grade and (.22 + .20 + .13 + .19) = 74% in 8th grade. The prevalence of ever using cigarettes is also high: 38% in 7th grade and 52% in 8th grade. The prevalence of marijuana use at 7th and 8th grades (21% and 32%, respectively), arrived at by summing the estimates for the ACM and ACIM stages, is greater than the prevalence for inhalant ever use (12%, 19%). The general tendency of transitioning out of the "no use" and "alcohol-only" stages into the AC, ACM, and ACIM stages is illustrated in Figure 5.3.

Table 5.15 Final δ Parameter Estimates for Four-Stage Model, White Males, 7th–8th Grade

Latent Stage	7th Grade	8th Grade
No use	.36	.26
Alcohol	.25	.22
Alcohol + cigarettes	.17	.20
Alcohol + cigarettes + marijuana	.09	.13
Alcohol + cigarettes + inhalants + marijuana	.12	.19

Note: Values do not sum to 1 due to rounding error.

Figure 5.3 Overall Prevalence of Substance Use Stages, White Males, 7th–8th Grade



Note: N = no use; A = alcohol only; AC = alcohol + cigarettes; ACM = alcohol + cigarettes + marijuana; ACIM = alcohol + cigarettes + inhalants + marijuana.

τ parameters: transition probabilities. The transition probability (τ) matrix is presented in Table 5.16. Entries along the diagonal reflect the probability of remaining in the same latent stage for both grades; for example, non-users in 7th grade have roughly a 73% chance of being in the non-user stage again in 8th grade, whereas individuals in the ACM stage in 7th grade are almost certain (97%) to remain in the same stage in 8th grade. This latter probability is evidence that marijuana use rarely, if ever, precedes inhalant use in this sample. The highest probability of transitioning to the ACIM stage is among individuals in the "alcohol + cigarette" (14%) stage, followed by those in the "alcohol only" (12%) stage. Notably, these individuals are far more likely to transition to the ACIM stage than to the ACM stage; individuals in the "alcohol only" stage in 7th grade have (.119/.008) 14.9 times

greater probability and individuals in the "alcohol + cigarette" stage have (.136/.065) 2.1 times greater probability of transitioning to the ACIM stage versus the ACM stage. Figure 5.4 displays the selected transition model representing gateway drug use sequencing among 7th–8th grade white males.

Table 5.16 τ Parameter Estimates, White Males, 7th–8th Grade

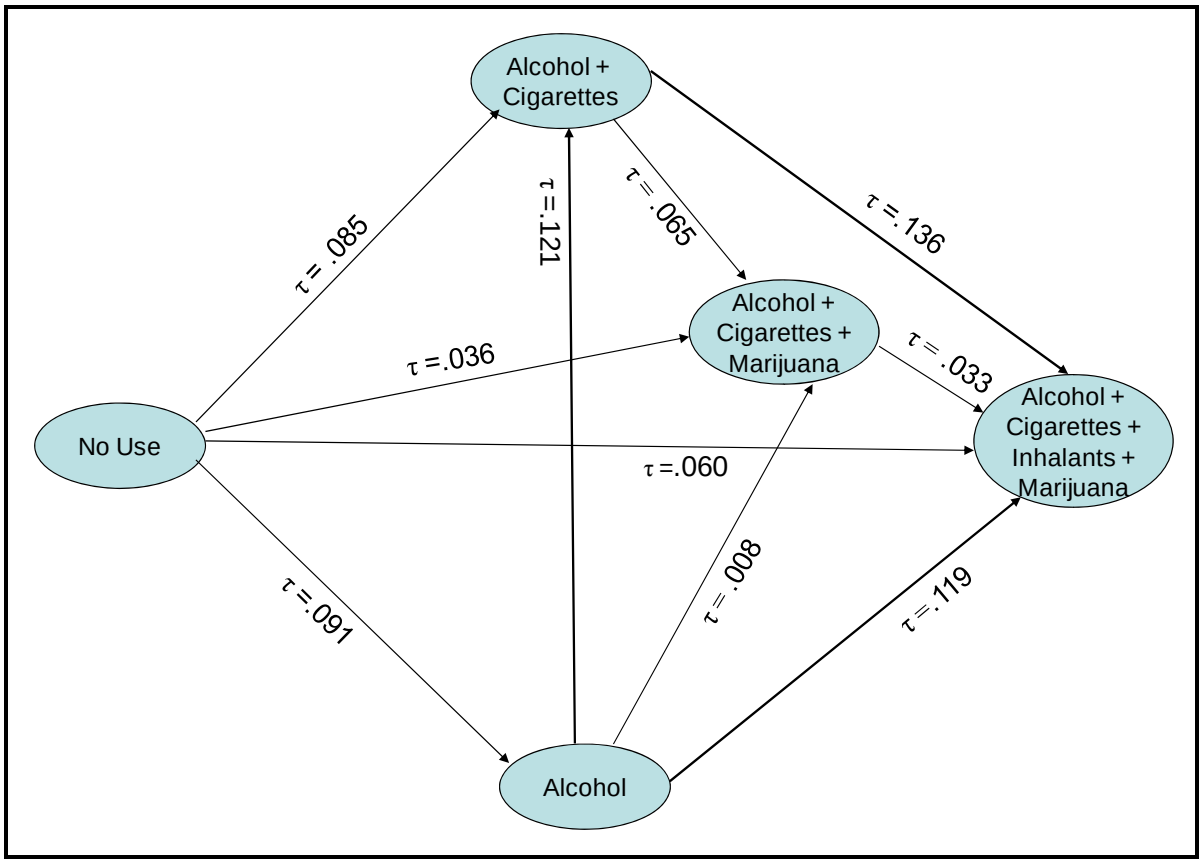
	Latent Stage in 8th Grade					
Latent Stage in 7th Grade	**N**	**A**	**AC**	**ACM**	**ACIM**	**Advance Rate**
No use (N)	.727 (.65, .80)	.091 (.03, .24)	.085 (.04, .15)	.036 (.01, .13)	.060 (.03, .11)	.273
Alcohol (A)	—	.752 (.65, .83)	.121 (.04, .27)	.008 (.00, .08)	.119 (.07, .19)	.248
Alcohol + cigarettes (AC)	—	—	.799 (.65, .90)	.065 (.00, .39)	.136 (.06, .27)	.201
Alcohol + cigarettes + marijuana (ACM)	—	—	—	.967 (.74, 1.0)	.033 (.00, .26)	.033
Alcohol + cigarettes + inhalants + marijuana (ACIM)	—	—	—	—	1.00	
Overall advance rate						.200

Notes: The τ parameter estimates represent the probability of transitioning to the column "latent stage in 8th grade," conditional on membership in the row "latent stage in 7th grade."

Dash (—) indicates that parameter was fixed to zero to represent the onset model.

Point estimates and 95% confidence intervals based on data augmentation.

Figure 5.4 Final Five-Stage Model for White Males, 7th–8th Grade, with Transitional Probability Estimates



These results are similar to those obtained for the 6th–7th grade sample, although for 7th–8th graders, the addition of the ACM latent stage appears to be necessary. As was the case for the 6th to 7th grade transition, results suggest that the gateway model can be extended to include inhalants (Research Question 1). Based on these results, Hypotheses 1.1 and 1.2 are rejected, as there is again no evidence that inhalant use precedes, or is a gateway to, alcohol, cigarette, or marijuana use for white males in the 7th–8th grade transition period.

5.2.2 White Females

5.2.2.1 6th–7th Grade Transition

Table 5.17 provides goodness-of-fit measures for various LTA models for white females transitioning from 6th to 7th grade. All of the G^2 values are substantially smaller than the degrees of freedom, indicating good overall fit. A seven-stage model was estimated, but a review of the ρ parameters suggested that two of the seven latent stages were redundant, so it was excluded. The AIC and BIC estimates designate different models as having the best model fit, with the AIC favoring the six-stage model and the BIC favoring the four-stage model. Cross-validation results are similarly ambiguous; the five-stage model cross-validates best for one of the random samples, and the four-stage model was the better fit for the other sample.

Table 5.17 Goodness-of-Fit for Various Models, White Females, 6th–7th Grade

Model	G^2 (df)	AIC	BIC	Cross-validation G^2_a	Cross-validation G^2_b
4 (N, A, AC, ACIM)	119.66 (230)	169.66	273.16	510.314	125.811
5 (N, A, C, AC, ACIM)	99.41 (221)	167.41	308.17	102.182	238.859
6 (N, A, C, AC, ACI, ACIM)	77.05 (212)	163.05	341.07	343.126	141.211

Notes: A = alcohol only; AC = alcohol + cigarettes; ACI = alcohol + cigarettes + inhalants; ACIM = alcohol + cigarettes + inhalants + marijuana; N = no use.

N = 464.

Model labels are based on the ρ parameters for the model.

Seven-stage model included two redundant latent stages (only six unique latent stages).

Given the lack of a clearly superior model based on the measures of relative fit, the ρ parameters for each model were examined to determine how well the latent stages are measured. In these baseline models, measurement is unconstrained: the ρ parameters are freely estimated (although the parameter estimates are held constant for both time periods).

Initial LTA estimates for the four- and five-stage models indicated that for the ACIM stage, measurement of the marijuana item was particularly weak; the item-response probability of a "yes" response was approximately .50 for the marijuana item, given membership in the ACIM latent stage. When a six-stage model was estimated, measurement was greatly improved. The lowest item-response probability in the six-stage model was .80. The probability of responding "yes" to each of the four drug use items, given membership in one of the six latent stages, is presented in Table 5.18.

Table 5.18 Freely Estimated ρ Parameters for Response "Yes," Six-Stage Model, White Females, 6th–7th Grade

	Latent Stage					
Item	**No Use**	**Alcohol**	**Cigarettes**	**Alcohol + Cigarettes**	**Alcohol + Cigarettes + Inhalants**	**Alcohol + Cigarettes + Inhalants + Marijuana**
Ever used alcohol	.02	**1.00**	.00	**.82**	**1.00**	**1.00**
Ever used cigarettes	.00	.00	**.84**	**.96**	**.90**	**1.00**
Ever used inhalants	.03	.05	.34	.00	**.85**	**.80**
Ever used marijuana	.00	.01	.05	.02	.00	**1.00**

Note: ρ parameters are constrained equal for both time points, so the estimates are the same for both grades.

The three models were analyzed using DA (with 100 imputations) to determine whether the ρ (Rho) parameter estimates were consistent across imputations. For the four-stage model, the interpretation changed; the ACIM stage was relabeled ACI because of the low probability of a "yes" response to the marijuana item. The five-stage model was consistent, although the measurement of the marijuana item remained poor. The six-stage model was consistent across imputations, and the measurement remained strong for each of the six stages. The six-stage model identified here is identical to the model identified for the 7th–8th grade sample (presented below), which provides some validation for the six-stage model here.

Although the relative measures of model fit failed to clearly delineate an optimal model, the six-stage model appears to provide a good representation of the data. It is consistent with the model obtained for the 7th–8th grade sample and is also consistent with the originally hypothesized model. Selection of this model allows for a direct assessment of the gateway relationship between inhalants, as part of the ACI latent stage, and marijuana, a component of the ACIM latent stage.

For these reasons, the six-stage model was selected as the final model for white females transitioning from 6th to 7th grade. The stages represent "no drug use" (N), "alcohol only" (A), "cigarettes only" (C), "alcohol + cigarettes" (AC), "alcohol + cigarettes + inhalants" (ACI), and "alcohol + cigarettes + inhalants + marijuana" (ACIM).

Based on these results, it appears that inhalants serve a more important role for white females than for white males. There is evidence that inhalant use may precede marijuana use for some white females transitioning from 6th to 7th grade. The presence of both an ACI and an ACIM stage means that the probability of transitioning from inhalant use to marijuana use can be directly assessed.

Parameter constraints for the final model. To obtain final parameter estimates for the six-stage model and to ensure model identification, constraints were placed on the measurement (ρ) and transition (τ) matrices as described previously for the white male samples. Table 5.19 illustrates the constraints placed on the ρ parameters, and Table 5.20 provides the parameter constraints for the τ matrix.

Table 5.19 Constraints on ρ Parameters for White Females, 6th–7th Grade

		Drug-Use Item			
	Latent Stage	**Ever Tried Alcohol**	**Ever Tried Cigarettes**	**Ever Tried Inhalants**	**Ever Tried Marijuana**
Probability of responding "no" given latent stage membership	No use	2	7	11	15
	A	5	7	11	15
	C	2	9	11	15
	AC	5	9	11	15
	ACI	5	9	13	15
	ACIM	5	9	13	17
Probability of responding "yes" given latent stage membership	No use	4	8	12	16
	A	6	8	12	16
	C	4	10	12	16
	AC	6	10	12	16
	ACI	6	10	14	16
	ACIM	6	10	14	18

Notes: A = alcohol only; AC = alcohol + cigarettes; ACI = alcohol + cigarettes + inhalants; ACIM = alcohol + cigarettes + inhalants + marijuana; C = cigarettes.

Each unique number is freely estimated. Same numbers are constrained to be equal. For instance, the probability of responding "Yes" to the alcohol ever use item given membership in any of the A, AC, ACI, or ACIM latent stages is constrained to be equal. This constraint ensures that the meaning of the alcohol use item is held constant across latent stages. Estimates are also constrained to be equal for both time points (measurement invariance).

Table 5.20 Constraints on τ Parameters for White Females, 6th–7th Grade

	No Use	**A**	**C**	**AC**	**ACI**	**ACIM**
No use	FR	FR	FR	FR	FR	FR
A	0	FR	0	FR	FR	FR
C	0	0	FR	FR	FR	FR
AC	0	0	0	FR	FR	FR
ACI	0	0	0	0	FR	FR
ACIM	0	0	0	0	0	FR

Note: A = alcohol; AC = alcohol + cigarettes; ACI = alcohol + cigarettes + inhalants; ACIM = alcohol + cigarettes + inhalants + marijuana; FR = freely estimated; 0 = fixed to zero (not estimated).

To ensure that the final model, with the applied constraints, is the proper solution for the six-stage model, the model was analyzed 100 separate times, using random start values. The originally identified six-stage model was the most frequently obtained result, with 58 out of 100 analyses producing the same result. It also had the lowest (best) G^2 of 219.60. Three alternate models also emerged, one with four distinct stages (N, A, C, AC) that was obtained

34 times (G^2 = 425.97) and two alternate six-stage models. The first, obtained six times (G^2 = 452.60), included the stages N, A, C, AC, AI, and AIM. The second was obtained twice (G^2 = 594.48) and included the stages N, A, C, AC, CI, and CIM.

The assumption of measurement invariance was tested via a χ^2 difference test for the difference between the model with the ρ parameters constrained to be equal (invariant) for both time points (G^2 = 109.049, 228 *df*) and the model without the measurement invariance constraint (G^2 = 97.594, 220 *df*). The difference of 11.46, with 8 degrees of freedom, is not significant (p = .177), supporting the decision to constrain measurement across times.

Final model results, white females, 6th–7th grade.

ρ parameters (model measurement). The final ρ parameter estimates and 95% confidence intervals are presented in Table 5.21. In general, the measurement of the latent stages is strong. The probability of responding "yes" to the inhalant use item, given membership in the ACI or ACIM latent stage, is .76, which is the lowest probability but still sufficiently large to indicate accurate measurement.

Table 5.21 Final ρ Parameter Estimates and 95% Confidence Intervals for Response "Yes," Six-Stage Model, White Females, 6th–7th Grade

	Latent Stage					
Item	**No Use**	**Alcohol**	**Cigarettes**	**Alcohol + Cigarettes**	**Alcohol + Cigarettes+ Inhalants**	**Alcohol + Cigarettes + Inhalants + Marijuana**
Ever used alcohol	.03 (.01, .09)	**.94 (.89, .97)**	.03 (.01, .09)	**.94 (.89, .97)**	**.94 (.89, .97)**	**.94 (.89, .97)**
Ever used cigarettes	.01 (.00, .04)	.01 (.00, .04)	**.92 (.84, .97)**	**.92 (.84, .97)**	**.92 (.84, .97)**	**.92 (.84, .97)**
Ever used inhalants	.05 (.03, .07)	.05 (.03, .07)	.05 (.03, .07)	.05 (.03, .07)	**.76 (.63, .86)**	**.76 (.63, .86)**
Ever used marijuana	.01 (.01, .02)	.01 (.01, .02)	.01 (.01, .02)	.01 (.01, .02)	.01 (.01, .02)	**.80 (.51, .95)**

Note: Point estimates and 95% confidence intervals based on data augmentation.

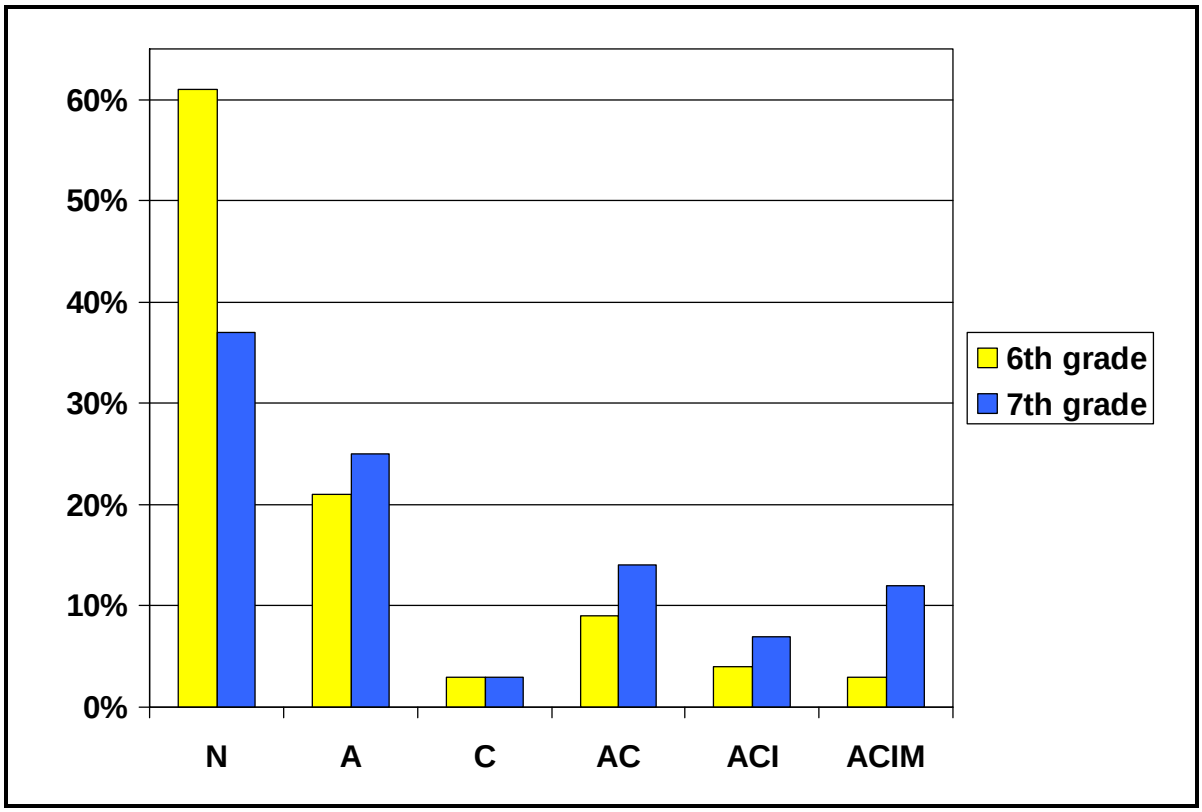
δ parameters: probabilities of latent stage membership. The estimated proportions of adolescents in each of the six latent substance use stages in 6th and 7th grades are presented in Table 5.22 and illustrated in Figure 5.5. In 6th grade, the majority of white females are estimated to be either non-users (61%) or to have tried only alcohol (21%). The estimated prevalence of never use in 7th grade is 37%, a sharp decrease from the 6th grade. Membership prevalence in all other stages, except "cigarettes only," increases from 6th to 7th grade. The increase is most pronounced for the ACIM stage. At both grades, prevalence of inhalant use is greater than prevalence of marijuana use; in 6th grade, the prevalence of inhalant use is approximately 7% (.04 + .03) while the prevalence of marijuana use is 3%. By 7th grade, these estimates increase to 19% (.07 + .12) and 12% for inhalant and marijuana use, respectively. This model suggested that the inclusion of a "cigarettes-only" stage was warranted. Prevalence in this stage is very low: only 3% at both grades.

Table 5.22 Final δ Parameter Estimates for Six-Stage Model, White Females, 6th–7th Grade

Latent Stage	6th Grade	7th Grade
No use	.61	.37
Alcohol	.21	.25
Cigarettes	.03	.03
Alcohol + cigarettes	.09	.14
Alcohol + cigarettes + inhalants	.04	.07
Alcohol + cigarettes + inhalants + marijuana	.03	.12

Note: Values do not sum to 1 due to rounding error.

Figure 5.5 Overall Prevalence of Substance Use Stages, White Females, 6th–7th Grade



Note: N = no use; A = alcohol only; C = cigarettes only; AC = alcohol + cigarettes; ACI = alcohol + cigarettes + inhalants; ACIM = alcohol + cigarettes + inhalants + marijuana.

τ parameters: transition probabilities. The τ matrix for white females transitioning from 6th to 7th grade is presented in Table 5.23, and the final six-stage transition model is illustrated in Figure 5.6. The overall probability of transitioning from one stage to a more advanced stage is .357. For non-users in 6th grade, the most common transition is to alcohol use, which is consistent with the literature on the gateway hypothesis and with the other samples in this study.

Table 5.23 τ Parameter Estimates, White Females, 6th–7th Grade

Latent Stage in 6th Grade	Latent Stage in 7th Grade						
	N	A	C	AC	ACI	ACIM	Advance Rate
No Use (N)	.618 (.55, .68)	.189 (.13, .26)	.025 (.00, .11)	.099 (.06, .16)	.012 (.00, .10)	.058 (.03, .10)	.382
Alcohol (A)	—	.671 (.54, .78)	—	.107 (.02, .37)	.155 (.04, .38)	.067 (.01, .27)	.329
Cigarettes (C)	—	—	.524 (.19, .84)	.117 (.01, .63)	.196 (.01, .71)	.163 (.01, .67)	.476
Alcohol + cigarettes (AC)	—	—	—	.666 (.43, .85)	.036 (.00, .30)	.298 (.12, .55)	.334
Alcohol + cigarettes + inhalants (ACI)	—	—	—	—	.691 (.14, .98)	.309 (.02, .86)	.309
Alcohol + cigarettes + inhalants + marijuana (ACIM)	—	—		—	—	1.00	
Overall advance rate							.357

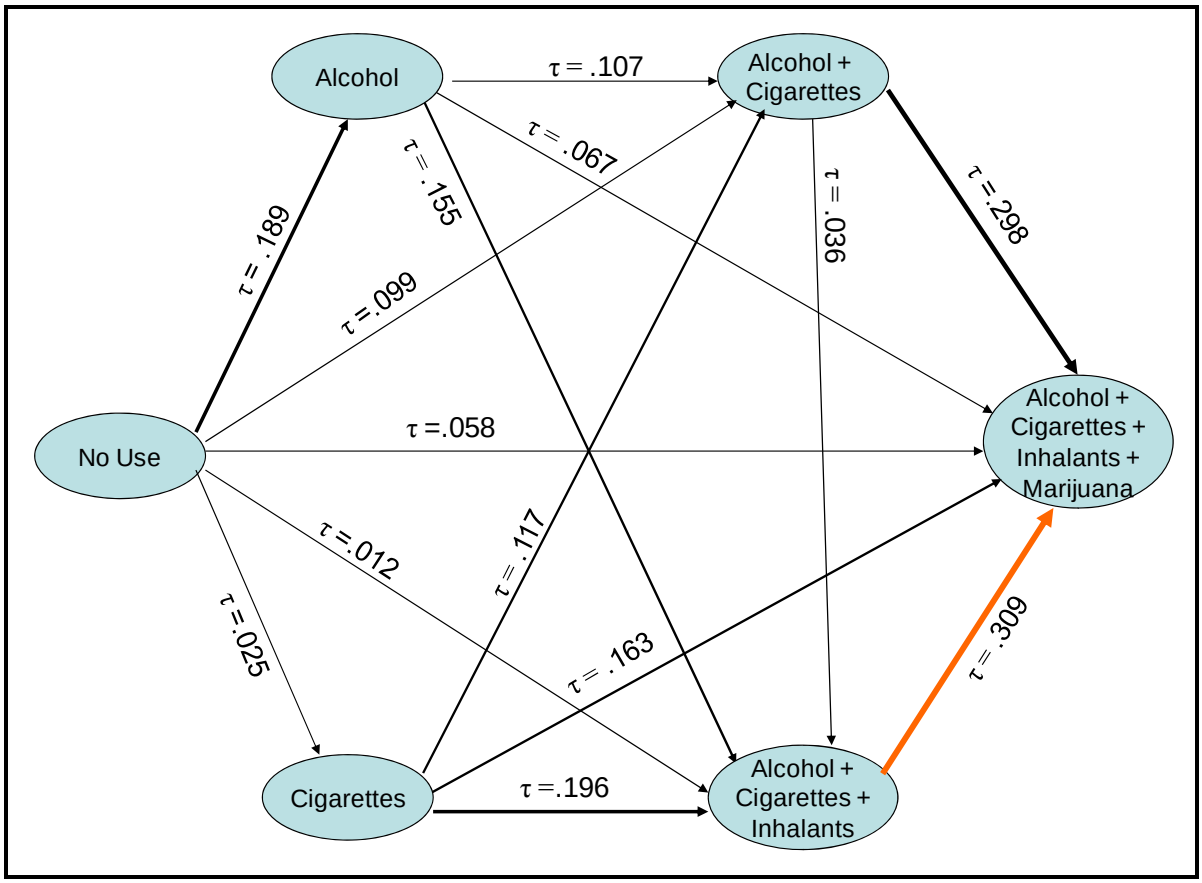
Notes: The τ parameter estimates represent the probability of transitioning to the column "latent stage by 7th grade," conditional on membership in the row "latent stage in 6th grade."

Dash (—) indicates that parameter was fixed to zero to represent the onset model.

Point estimates and 95% confidence intervals based on data augmentation.

Individuals in the alcohol-only stage in 6th grade are 2.3 times more likely to transition to the ACI stage than to the ACIM stage; individuals in the cigarettes-only stage in 6th grade are 1.2 times more likely to transition to the ACI stage than to the ACIM stage. Conversely, individuals in the AC stage in 6th grade are 8.3 times more likely to transition to the ACIM stage than to the ACI stage in 7th grade.

Figure 5.6 Final Six-Stage Model for White Females, 6th–7th Grade, with Transitional Probability Estimates



Inhalants are present in two of the six stages for white females transitioning from 6th to 7th grade, suggesting that the gateway drug use sequence can be extended to include inhalants for this group. The presence of both an ACI and an ACIM stage allows for an assessment of the transition probability from inhalant use in 6th grade to marijuana use in 7th grade. Individuals in the ACI stage in 6th grade had a .31 (31%) probability of transitioning to the ACIM stage by 7th grade. Given that there is no other stage that includes marijuana use, these results suggest that while the ever use of inhalants (in conjunction with alcohol and cigarette ever use) increases the probability of transitioning to marijuana use, there is no

evidence that marijuana use precedes or increases the likelihood of transitioning to inhalant use.

These results therefore provide support for Hypothesis 1.1: inhalant use appears to precede marijuana use for a significant number of white female adolescents transitioning from the 6th to 7th grade. To examine Hypothesis 1.2, which posits that inhalants operate as a partial gateway to marijuana use, a series of equations, based on an operational definition of the gateway hypothesis, are tested in the following section.

Is inhalant use a gateway to marijuana use for white females in 6th–7th grade? For a *complete* gateway relationship between inhalants and marijuana to exist, the probability of trying marijuana at Time 2, conditional on *not* having tried inhalants at Time 1, would equal zero; in other words, everyone who tries marijuana at Time 2 would have tried inhalants at Time 1. Additionally, the probability of trying marijuana at Time 2, conditional on having tried inhalants at Time 1, would be greater than zero, suggesting that inhalant use at Time 1 has increased the probability of marijuana use at Time 2 (Maldonado-Molina, 2005). The first condition is not directly testable in this case because the only marijuana use stage also includes inhalants. So while the large, direct transition probabilities from the "cigarettes-only" and "alcohol + cigarettes" stages to the ACIM stage suggests that inhalant use may not always precede marijuana use, it also appears that marijuana use is rarely, if ever, used without having also previously or concurrently used inhalants in this sample of white female adolescents.

The absence of an ACM stage suggests that inhalants do always precede marijuana use for this sample; the direct AC to ACIM transition may exist because the transition from inhalants to marijuana use is obscured by the spacing of measurements in this analysis. In

other words, it is possible that all those in the ACIM stage first used inhalants, including those who appear to transition directly from the AC stage, but this not directly verifiable by these data.

A *partial* gateway relationship between inhalants and marijuana exists if the risk for marijuana use is increased once inhalants are used, even if inhalant use does not universally precede marijuana use. Furthermore, evidence of a partial gateway relationship between inhalants and marijuana requires that having tried marijuana is not associated with an increased risk of inhalant use (Maldonado-Molina, 2005). The results indicate that using inhalants (ACI) in 6th grade is associated with a high (.309) probability of transitioning to marijuana use (ACIM) by 7th grade. Based on this model, there is no evidence that using marijuana in 6th grade increases the probability of using inhalants in 7th grade.

A total of five equations are used to assess a complete gateway relationship. Because the complete gateway relationship has been eliminated as an option based on the final model selected, the final two equations (4 and 5) are tested to determine whether a partial gateway relationship exists:

$$P(mar_{t'}|inh_t) > P(mar_{t'}|\overline{inh_t}) \qquad \text{Equation 4}$$

$$P(inh_{t'}|mar_t) < P(inh_{t'}|\overline{mar_t}) \qquad \text{Equation 5}$$

where

$P(mar_{t'}|inh_t)$ is the probability of trying marijuana at a later time conditional on having tried inhalants at an earlier time,

$P(mar_{t'}|\overline{inh_t})$ is the probability of trying marijuana at a later time conditional on not having tried inhalants at an earlier time,

$P(inh_{t'}|mar_t)$ is the probability of trying inhalants at a later time conditional on having tried marijuana at an earlier time, and

$P(inh_{t'}|\overline{mar_t})$ is the probability of trying inhalants at a later time conditional on not having tried marijuana at an earlier time.

Equation 4 tests whether the probability of trying marijuana at a later time conditional on having tried inhalants at an earlier time is greater than the probability of trying marijuana at a later time conditional on not having tried inhalants at an earlier time. The first part of this equation was calculated by estimating the overall probability of membership in the stage that includes the use of marijuana (ACIM) in 7th grade, conditional on having used inhalants (ACI) in 6th grade.

This estimate is derived by multiplying the conditional probability of transitioning from ACI to ACIM (.309) times the estimated proportion of the overall sample that has tried inhalants but not marijuana—those who were in the ACI stage at baseline (6th grade) as represented by the δ (latent stage membership) estimate for the ACI stage in 6th grade (.036). The resulting number represents the overall probability of transitioning from ACI to ACIM in this sample. In other words, 3.6% of the sample was estimated to be in the ACI stage at 6th grade. Of these, 30.9% were estimated to transition to the ACIM stage. This product (.036* .309 = 0.011) is then divided by the overall probability of using inhalants in 6th grade, which is the sum of the prevalence (δ) estimates for the ACI and the ACIM stages in 6th grade (.036 + .032 = .068); including this estimate in the equation accounts for the fact that some adolescents have used both inhalants and marijuana at 6th grade. So, (.036*.309)/.068 = **.164**.

The second part of Equation 4 was estimated by calculating the probability of membership in the ACIM stage in 7th grade, conditional on membership in all of the stages *except* the ACI stage. This involves multiplying each of the transition probabilities from stages that do not include inhalants (N, A, C, AC) to marijuana (ACIM) by the baseline

probability (δ) of being in each of those respective stages. So, N (.606 * .058) + A (.206 * .067) + C (.028 * .163) + AC (.092 * .298) = .081. This number is then divided by the probability of not using inhalants in 6th grade (1 – 0.068 = .932). So, .081/.932 = **.087**. Based on the results for Equation 4 (.164 > .087), there is evidence to suggest a partial gateway relationship between inhalants and marijuana, direct support for Hypothesis 1.2.

Equation 5 does not need to be estimated in this case—there is no evidence that marijuana use precedes inhalant use in this sample, and therefore no stages are present in the model to facilitate testing Equation 5. The probability of using inhalants at 7th grade, conditional on having used marijuana at 6th grade equals zero and is clearly less than the probability of transitioning to inhalant use at 7th grade conditional on not using marijuana at 6th grade (which is the sum of the transition probabilities from the N, A, C, and AC stages to the ACI and the ACIM stages).

5.2.2 7th–8th Grade Transition

Table 5.24 presents goodness-of-fit measures for various LTA models for white females transitioning from 7th to 8th grade. This is the one instance in the overall study where a clearly superior model, based on overall and relative fit measures and on the measurement properties of the model, is selected. Both the AIC and BIC suggest that the six-stage model provides the best fit to the data; the additional step of cross-validation was not taken because of the clear superiority of this model. The G^2 value is substantially smaller than the degrees of freedom, which is unique among the four 7th–8th grade samples. The stages were easily identifiable and well-measured and are the same as those identified for the 6th–7th grade white female sample: “no drug use” (N), “alcohol only” (A), “cigarettes only”

(C), "alcohol + cigarettes" (AC), "alcohol + cigarettes + inhalants" (ACI), and "alcohol + cigarettes + inhalants + marijuana" (ACIM).

Table 5.24 Goodness-of-Fit for Various Models, White Females, 7th–8th Grade

Model	G^2 (df)	AIC	BIC
4 (N, A, AC, ACIM)	255.99 (230)	305.99	427.51
5 (N, A, C, AC, ACIM)	216.64 (222)	282.64	443.04
6 (N, A, C, AC, ACI, ACIM)	135.04 (212)	217.04	416.33

Notes: A = alcohol; AC = alcohol + cigarettes; ACIM = alcohol + cigarettes + inhalants + marijuana; ACM = alcohol + cigarettes + marijuana; AIC = alcohol + inhalants + cigarettes; C = cigarettes; N = no use.
N = 954.
Model labels are based on the ρ parameters for the model.
Cross-validation was not performed because of the clear superiority of the six-stage model.
Seven-stage model included two redundant latent stages (only six unique latent stages).

For the six-stage model, the probability of responding "yes" to each of the four drug use items, given membership in one of the four stages, is presented in Table 5.25. When this six-stage model was analyzed using DA (with 100 imputations), the ρ (Rho) parameter estimates suggested consistent measurement of the six latent stages across imputations.

Table 5.25 Freely Estimated ρ Parameters for Response "Yes," Six-Stage Model, White Females, 7th–8th Grade

	Latent Stage					
Item	No Use	Alcohol	Cigarettes	Alcohol + Cigarettes	Alcohol + Cigarettes + Inhalants	Alcohol + Cigarettes + Inhalants + Marijuana
Ever used alcohol	.00	**.88**	.32	**1.00**	**.92**	**1.00**
Ever used cigarettes	.01	.05	**.95**	**1.00**	**.82**	**1.00**
Ever used inhalants	.02	.02	.09	.07	**.96**	**.59**
Ever used marijuana	.00	.00	.08	.05	.26	**.96**

Note: ρ parameters are constrained equal for both time points, so the estimates are the same for both grades.

As discussed for the 6th–7th grade sample, the selected model allows for an examination of the potential partial gateway relationship between inhalant use and marijuana use. These preliminary results suggest that inhalants may play an important role in drug use sequencing for the females in this study.

Parameter constraints for the final model. To obtain final parameter estimates for the six-stage model and to ensure model identification, constraints were placed on the measurement (ρ) and transition (τ) matrices in the same way as for the 6th–7th grade model. Table 5.26 illustrates the constraints placed on the ρ parameters, and Table 5.27 provides the parameter constraints for the τ matrix.

Table 5.26 Constraints on *ρ* Parameters for White Females, 7th–8th Grade

		Drug-Use Item			
	Latent Stage	**Ever Tried Alcohol**	**Ever Tried Cigarettes**	**Ever Tried Inhalants**	**Ever Tried Marijuana**
Probability of responding "no" given latent stage membership	No Use	2	7	11	15
	A	5	7	11	15
	C	2	9	11	15
	AC	5	9	11	15
	ACI	5	9	13	15
	ACIM	5	9	13	17
Probability of responding "yes" given latent stage membership	No Use	4	8	12	16
	A	6	8	12	16
	C	4	10	12	16
	AC	6	10	12	16
	ACI	6	10	14	16
	ACIM	6	10	14	18

Notes: A = alcohol only, AC = alcohol + cigarettes, ACIM = alcohol + cigarettes + inhalants + marijuana.
Each unique number is freely estimated. Same numbers are constrained to be equal. For instance, the probability of responding "Yes" to the alcohol ever use item given membership in any of the A, AC, ACI, or ACIM latent stages is constrained to be equal. This constraint ensures that the meaning of the alcohol use item is held constant across latent stages. Estimates are also constrained to be equal for both time points (measurement invariance).

Table 5.27 Constraints on *τ* Parameters for White Females, 7th–8th Grade

	No Use	**A**	**C**	**AC**	**ACI**	**ACIM**
No use	FR	FR	FR	FR	FR	FR
A	0	FR	0	FR	FR	FR
C	0	0	FR	FR	FR	FR
AC	0	0	0	FR	FR	FR
ACI	0	0	0	0	FR	FR
ACIM	0	0	0	0	0	FR

Notes: A = alcohol; AC = alcohol + cigarettes; ACI = alcohol + cigarettes + inhalants; ACIM = alcohol + cigarettes + inhalants + marijuana; FR = freely estimated; 0 = fixed to zero (not estimated)

To ensure that the final model, with the applied constraints, is the proper solution for the six-stage model, the model was analyzed 100 separate times, using random start values. The selected six-stage model was the most frequently obtained result, with 55 out of 100 analyses producing the same result, and had the lowest (best) G^2 of 648.25. Four alternate models also emerged. The second most frequently derived model (36 times) included just four latent stages: "no use," "alcohol only," "cigarettes only," and "alcohol + cigarettes." The G^2 for this model was 1,009.25. The three remaining models had G^2 values of 1,106.99 (7 times), 1,347.39 (1 time), and 1563.98 (1 time). As both the most frequently obtained and best fitting model, the selected six-stage model is retained for final parameter estimation.

The assumption of measurement invariance was tested via a χ^2 difference test for the difference between the model with the ρ parameters constrained to be equal (invariant) for both time points (G^2 = 188.020, 228 *df*) and the model without the measurement invariance constraint (G^2 = 183.444, 220 *df*). The difference of 4.58, with 8 degrees of freedom, is not significant (p = .802), supporting the decision to constrain measurement across times.

Final model results, white females, 7th–8th grade.

ρ parameters (model measurement). The final ρ parameter estimates and 95% confidence intervals are presented in Table 5.28. Measurement is strong across the latent stages, although the inhalant use item is less well measured (as is the case for the other samples as well). Reviewing the original freely estimated ρ parameters (see Table 5.25), membership in the ACI stage is associated with a very high probability of responding yes to the inhalant use item (.96) while membership in the ACIM stage is associated with a .59 probability of responding yes to the inhalant use item. With the constraints, the interpretation of the ρ parameters for inhalants is as follows: given membership in one of the latent stages

Table 5.28 Final ρ Parameter Estimates for Response "Yes," Six-Stage Model, White Females, 7th–8th Grade

	Latent Stage					
Item	**No Use**	**Alcohol**	**Cigarettes**	**Alcohol + Cigarettes**	**Alcohol + Cigarettes+ Inhalants**	**Alcohol + Cigarettes + Inhalants + Marijuana**
Ever used	.05	**.94**	.05	**.94**	**.94**	**.94**
alcohol	(.02, .11)	**(.91, .96)**	(.02, .11)	**(.91, .96)**	**(.91, .96)**	**(.91, .96)**
Ever used	.02	.02	**.93**	**.93**	**.93**	**.93**
cigarettes	(.01, .04)	(.01, .04)	**(.90, .96)**	**(.90, .96)**	**(.90, .96)**	**(.90, .96)**
Ever used	.03	.03	.03	.03	**.64**	**.64**
inhalants	(.02, .04)	(.02, .04)	(.02, .04)	(.02, .04)	**(.58, .70)**	**(.58, .70)**
Ever used	.01	.01	.01	.01	.01	**.85**
marijuana	(.00, .02)	(.00, .02)	(.00, .02)	(.00, .02)	(.00, .02)	**(.75, .93)**

Note: Point estimates and 95% confidence intervals based on data augmentation.

that include inhalants (ACI and ACIM), the probability of responding "yes" to the inhalant use item is .64.

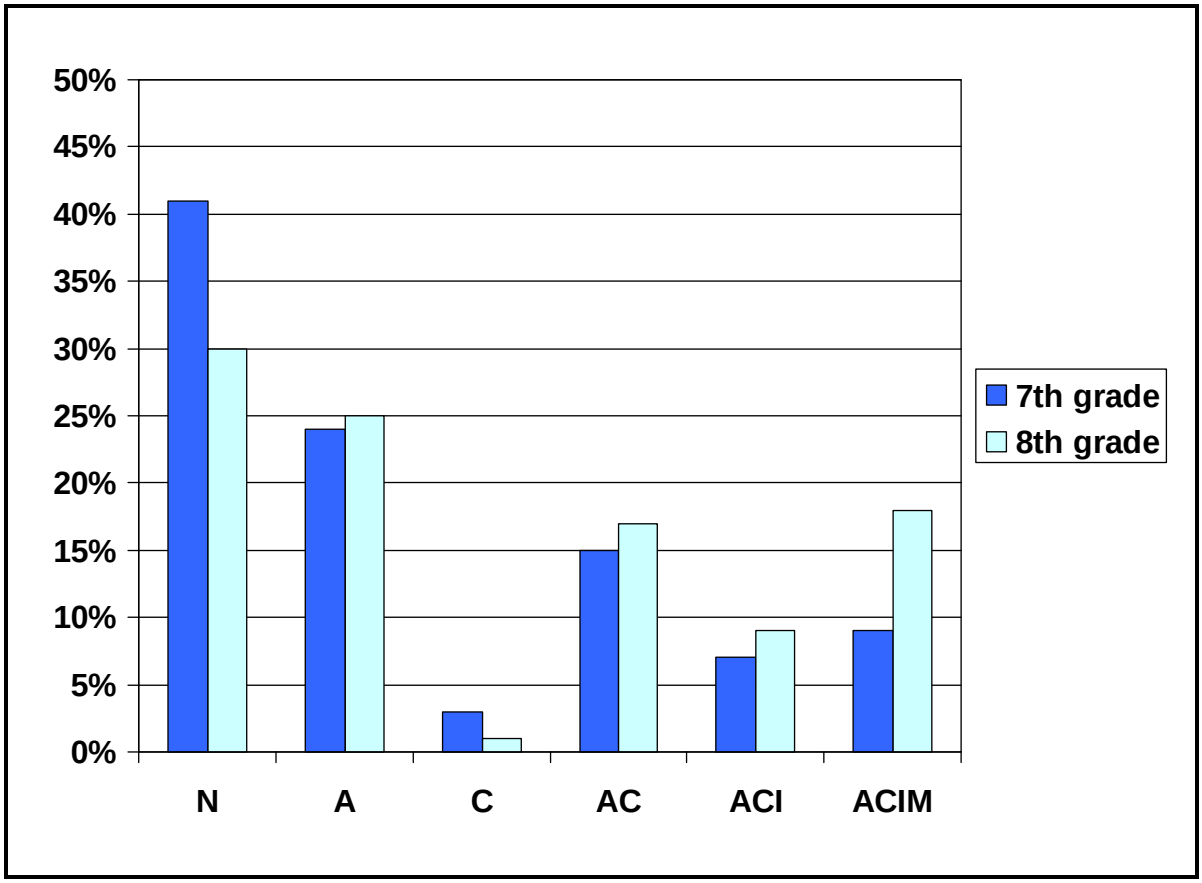
δ parameters: probabilities of latent stage membership. Table 5.29 and Figure 5.7 show the estimated proportion of adolescents in each of the six latent substance use stages in 7th and 8th grades. In 7th grade, 41% of the white females in the sample are expected to be in the "no use" latent stage, while one-quarter are expected to be in the alcohol-only stage. Based on this model, at baseline (7th grade), the overall estimated prevalence is 16% for inhalant use and 9% for marijuana use. Both the ACI and ACIM stages increase in prevalence from 7th to 8th grade.

Table 5.29 Final δ Parameter Estimates for Six-Stage Model, White Females, 7th–8th Grade

Latent Stage	7th Grade	8th Grade
No use	.41	.30
Alcohol	.24	.25
Cigarettes	.03	.01
Alcohol + cigarettes	.15	.17
Alcohol + cigarettes + inhalants	.07	.09
Alcohol + cigarettes + inhalants + marijuana	.09	.18

Note: Values do not sum to 1 due to rounding error.

Figure 5.7 Overall Prevalence of Substance Use Stages, White Females, 7th–8th Grade



Note: N = no use; A = alcohol only; C = cigarettes only; AC = alcohol + cigarettes; ACI = alcohol + cigarettes + inhalants; ACIM = alcohol + cigarettes + inhalants + marijuana.

τ parameters: transition probabilities. The τ parameters express the probability of transitioning from one latent stage to another between grade 7 and grade 8. The τ matrix is presented in Table 5.30, and the six-stage transition model is illustrated in Figure 5.8.

Table 5.30 τ Parameter Estimates, White Females, 7th–8th Grade

Latent Stage in 7th grade	Latent Stage in 8th grade						Advance Rate
	N	A	C	AC	ACI	ACIM	
No use (N)	.721 (.66, .78)	.178 (.13, .24)	.007 (.00, .06)	.044 (.02, .11)	.021 (.00, .12)	.030 (.01, .06)	.279
Alcohol (A)	—	.743 (.66, .81)	-	.119 (.06, .22)	.065 (.01, .21)	.073 (.04, .14)	.257
Cigarettes (C)	—	—	.496 (.23, .76)	.185 (.01, .69)	.060 (.00, .42)	.259 (.05, .66)	.504
Alcohol + cigarettes (AC)	—	—	—	.688 (.56, .79)	.015 (.00, .13)	.297 (.20, .42)	.312
Alcohol + cigarettes + inhalants (ACI)	—	—	—	—	.826 (.43, .98)	.174 (.02, .57)	.174
Alcohol + cigarettes + inhalants + marijuana (ACIM)	—	—		—	—	1.00	
Overall advance rate							.253

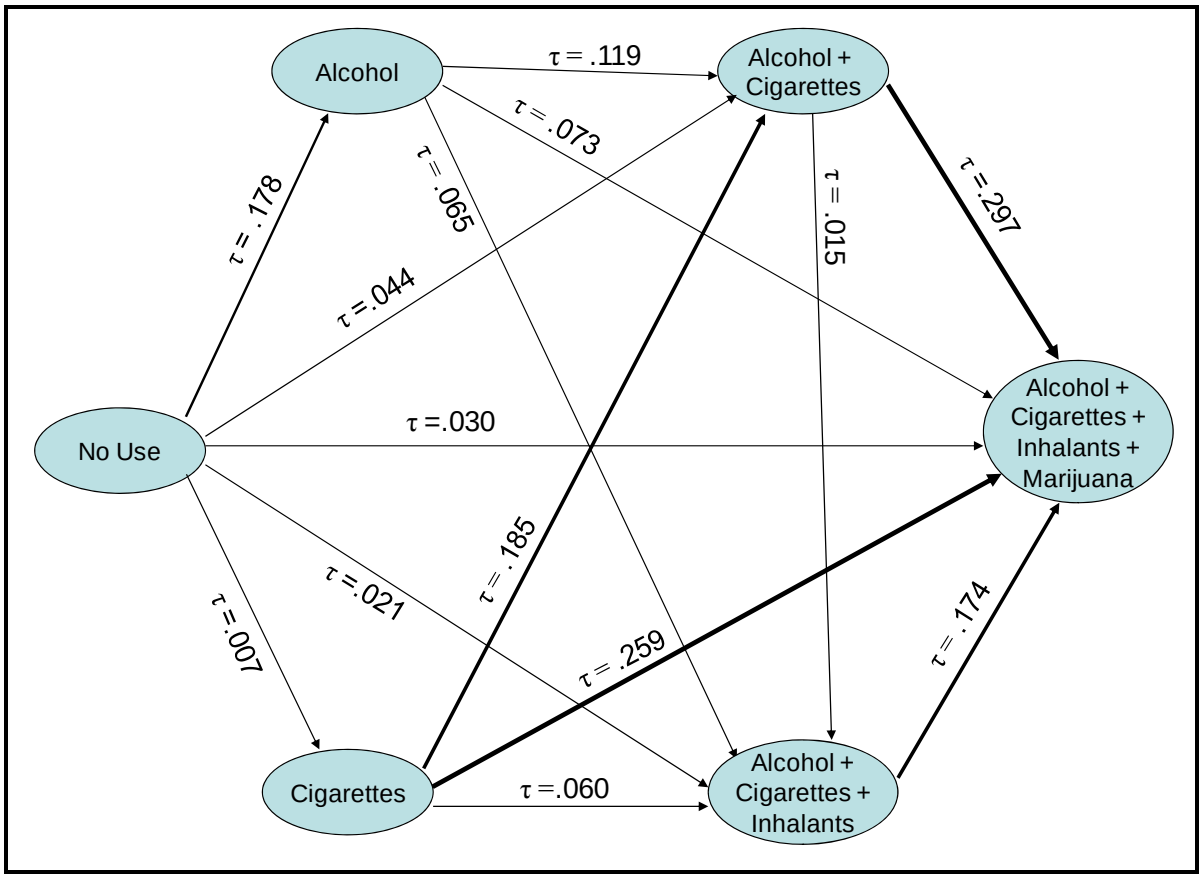
Notes: The τ parameter estimates represent the probability of transitioning to the column "latent stage in 8th grade," conditional on membership in the row latent stage in 7th grade.

Dash (—) indicates that parameter was fixed to zero to represent the onset model.

Point estimates and 95% confidence intervals based on data augmentation.

These results indicate that transitions from any of the latent stages to inhalant use (ACI) are relatively small for the 7th–8th grade sample, suggesting that a majority of the individuals in the ACI stage were in it prior to this transition period. Individuals in the "cigarettes-only" and "alcohol + cigarettes" stages have relatively high probabilities of transitioning to the ACIM stage by the 8th grade: 26% and 30%, respectively. The transition from ACI to ACIM is moderately large (.174) but not as large as the transition in the 6th–7th grade model.

Figure 5.8 Final Six-Stage Model for White Females, 7th–8th Grade, with Transitional Probability Estimates



The same latent transition model identified for white females transitioning from 6th to 7th grade is found here for the 7th to 8th grade transition. Again, inhalants are present in two of the six stages for white females transitioning from 6th to 7th grade, suggesting that the gateway drug use sequence can be extended to include inhalants for this group. Individuals in the ACI stage in 7th grade had a .17 (17%) probability of transitioning to the ACIM stage by 8th grade, a lower probability than for the earlier transition (.31) but still significant. Given that there is no other stage that includes marijuana use, these results suggest that while the ever use of inhalants (in conjunction with alcohol and cigarette ever use) increases the probability of transitioning to marijuana use, there is no evidence that marijuana use precedes

or increases the likelihood of transitioning to inhalant use, thus providing evidence in support of Hypothesis 1.1.

Is inhalant use a gateway to marijuana use for white females in 7th–8th grade?

The presence of an ACI stage and the absence of an ACM stage again suggest that inhalant use precedes marijuana use for white females. Using the same equations described for white females in the 6th–7th grade sample, it is possible to formally assess whether inhalant use in 7th grade is a partial gateway to marijuana use in the 8th grade. This involves testing whether the probability of using marijuana in 8th grade conditional on having used inhalants in 7th grade is greater than the probability of using marijuana in 8th grade conditional on *not* having used inhalants in 7th grade. The first step was to estimate the probability of membership in the stage that includes the use of marijuana (ACIM) in 8th grade, conditional on having used inhalants (ACI) in 7th grade (.073 * .174), divided by the probability of using inhalants in 6th grade (.165). So, (.073*.174)/.165 = .077.

The second step was to calculate the probability of membership in the ACIM stage in 8th grade, conditional on membership in all of the stages *except* the ACI stage. So, N(.410 * .030) + A (.244 * .073) + C (.028 * .259) + AC (.154 * .297) = .083, divided by the probability of not using inhalants in 6th grade (.835). So, .083/.835 = .099.

Comparing these two estimates as described in Equation 4 (.077 < .099), it appears that while inhalant use is associated with an increased probability of transitioning to marijuana use, there is not evidence to support the hypothesis (1.2) that there is a partial gateway relationship between inhalants and marijuana, given the criteria used in this study.

5.2.3 African American Males

5.2.3.1 6th–7th Grade Transition

Table 5.31 provides goodness-of-fit measures for various LTA models for African American males transitioning from 6th to 7th grade. A three-stage model was included because of the instability of the estimates for the other models, which suggested an even more parsimonious model was needed. It is interesting to note that all of the models include a stage that was not present for the other samples: "Cigarettes + Marijuana." Also, inhalants do not appear in any of the stages for any of the tested models.

Table 5.31 Goodness-of-Fit for Various Models, African American Males, 6th–7th Grade

Model[a]	G^2 (df)	AIC	BIC	Cross-validation G^2_a	Cross-validation G^2_b
3 (N, AC, ACM)	200.66 (238)	234.66	300.86	243.981	172.343
4 (N, AC, CM, ACM)	173.68 (232)	219.68	310.62	240.787	171.441
5 (N, C, AC, CM, ACM)	150.58 (222)	216.58	345.09	248.790	165.185
6 (N, A, C, AC, CM, ACM)	131.08 (213)	213.08	372.75	249.606	179.826

Notes: A = alcohol only, AC = alcohol + cigarettes, ACM = alcohol + cigarettes + marijuana; C = cigarettes; N = no use.

N = 363.

Model labels are based on the ρ parameters for the model.

As a general rule, G^2 values that are less than the degrees of freedom suggest a good overall fit. In this case, all of the models appear to fit the data well. The AIC identifies the six-stage model as best-fitting, whereas the BIC favors the three-stage model. The four-stage model has the lowest cross-validation G^2 for one of the random split samples, whereas the five-stage model is lower for the other. Clearly, a good deal of ambiguity is present, and selection of the model requires an examination of the measurement properties and consistency.

When freely estimated (no constraints), the ρ parameters for the three-stage model indicate that it has the best measurement of the candidate models. These estimates are presented in Table 5.32. The latent stage labels are based on the pattern of ρ estimates.

Table 5.32 Freely Estimated ρ Parameters for Response "Yes," Four-Stage Model, African American Males, 6th–7th Grade

	Latent Stage		
Item	**No Use**	**Alcohol + Cigarettes**	**Alcohol + Cigarettes + Marijuana**
Ever used alcohol	.13	**.77**	**.74**
Ever used cigarettes	.07	**.68**	**.92**
Ever used inhalants	.04	.16	.36
Ever used marijuana	.02	.11	**1.00**

Note: ρ parameters are constrained equal for both time points, so the estimates are the same for both grades.

Measurement of the latent stages for the other models (four-, five-, and six-stage models) indicated that measurement of certain latent stages was not strong, although the stages were clearly identifiable and not redundant. To examine how consistent these estimates were, DA was conducted with 100 imputations. The results of these runs provided support for the three-stage model. The ρ (Rho) parameter estimates across the imputed data sets for the three-stage model suggest that the measurement of the three latent stages is consistent across imputations; that is, the same three stages are present, and the measurement quality is similar to that obtained in the original LTA.

The more complex models were unstable across the imputed data sets. In fact, for each model, the same three stages are the only ones that remain clearly identifiable across the imputed data sets. Despite initial evidence that additional stages may be warranted, the data appear to only support three stages that are stable. Based on this collection of evidence, for African American males transitioning from 6th to 7th grade, the three-stage model was

selected as the final model. The stages represent "no drug use" (N), "alcohol + cigarettes" (AC), and "alcohol, cigarettes, and marijuana" (ACM).

These preliminary results suggest that for African American males transitioning from 6th to 7th grade in this sample, the gateway drug use model cannot be expanded to include inhalants. Indeed, although there are clearly African American males who have used inhalants in this sample (based on descriptive frequencies presented in Table 4.5), the proportion appears to be so low, and/or the consistency of reporting inhalant use so poor, that inhalants are excluded from the models. The results do suggest a potential "new" stage ("Cigarettes + Marijuana") although unstable estimates favored a more parsimonious, three-stage model.

Parameter Constraints for the Final Model. To obtain final parameter estimates for the three-stage model and to ensure model identification, constraints were placed on the measurement (ρ) and transition (τ) matrices. Table 5.33 illustrates the constraints placed on the ρ parameters. The matrix is constrained so that the probability of responding "yes" and the probability of responding "no" to a drug use item, conditional on latent stage membership, is estimated. In this case, a total of 14 parameters are estimated, as opposed to a total possible number of 48 (24 x 2 time points) parameters.

Table 5.33 Constraints on ρ Parameters for African American Males, 6th–7th Grade

		Drug-Use Item			
	Latent Stage	Ever Tried Alcohol	Ever Tried Cigarettes	Ever Tried Inhalants	Ever Tried Marijuana
Probability of responding "no" given latent stage membership	No use	2	7	11	15
	AC	5	9	11	15
	ACM	5	9	11	17
Probability of responding "yes" given latent stage membership	No use	4	8	12	16
	AC	6	10	12	16
	ACM	6	10	12	18

Note: AC = alcohol + cigarettes; ACM = alcohol + cigarettes + marijuana.

Each unique number is freely estimated. Same numbers are constrained to be equal. For instance, the probability of responding "Yes" to the alcohol ever use item given membership in either the A or ACM latent stage is constrained to be equal. This constraint ensures that the meaning of the alcohol use item is held constant across latent stages. Estimates are also constrained to be equal for both time points (measurement invariance).

The transition matrix (τ) (Table 5.34) reflects the fact that this is an onset (ever-use) model. In this case, an individual is free to progress to a later drug use stage but cannot revert to an earlier stage (e.g., someone who reported ever using alcohol at Time 1 cannot be in the "no use" stage at Time 2). Based on the gateway hypothesis, it is assumed that while an individual can transition from "no use" to one of the more advanced stages, the probability of transitioning will be greater for those who have tried alcohol or alcohol and cigarettes.

Table 5.34 Constraints on τ parameters for African American Males, 6th–7th Grade

	No Use	AC	ACM
No use	FR	FR	FR
AC	0	FR	FR
ACM	0	0	FR

Notes: AC = alcohol + cigarettes; ACM = alcohol + cigarettes + marijuana; FR = freely estimated; 0 = fixed to zero (not estimated).

To ensure that the final model, with the applied constraints, is the proper solution for the three-class model, the model was analyzed 100 separate times, using random start values. Two models emerged: the selected three-stage model and an alternate two-stage model (N +

AC). The three-stage model was the most frequent solution; 63 of the 100 analyses supported the three-stage model. Additionally, the G^2 associated with the three-stage model (291.48) was lower than the G^2 associated with the two-stage model (305.90).

The assumption of measurement invariance was tested via a χ^2 difference test for the difference between the model with the ρ parameters constrained to be equal (invariant) for both time points (G^2 = 257.423, 243 *df*) and the model without the measurement invariance constraint (G^2 = 243.200, 236 *df*). The difference of 14.223, with 7 degrees of freedom, is not significant (p = .0572), supporting the decision to constrain measurement across times.

Final model results, African American males, 6th–7th grade.

To obtain final parameter estimates and standard errors, DA was conducted. Whereas DA was used earlier to assess the stability of the unconstrained model across 100 imputed data sets, here DA was applied to the final constrained model, and the results were combined to generate final parameter estimates that take into account the uncertainty present across the imputed data sets.

ρ parameters (model measurement). The final ρ parameter estimates, specifically the probability of responding "yes" to each item, along with 95% confidence intervals, are presented in Table 5.35. The values were constrained to be equal across time (measurement invariance), so the ρ parameters are the same for both time points. To achieve identification and model stability, additional constraints were imposed such that only two parameters are estimated for each item; the probability of responding "no" can be obtained by subtracting the parameters in Table 5.35 from 1.00.

Table 5.35 Final ρ Parameter Estimates for Response "Yes," Four-Stage Model, African American Males, 6th–7th Grade

	Latent Stage		
Item	**No Use**	**Alcohol + Cigarettes**	**Alcohol + Cigarettes + Marijuana**
Ever used alcohol	.21 (.17, .27)	**.77 (.69, .83)**	**.77 (.69, .83)**
Ever used cigarettes	.08 (.04, .14)	**.88 (.78, .94)**	**.88 (.78, .94)**
Ever used inhalants	.13 (.10, .15)	.13 (.10.15)	.13 (.10.15)
Ever used marijuana	.04 (.02, .07)	.04 (.02, .07)	**.84 (.54, .97)**

Note: Point estimate and 95% confidence intervals based on data augmentation.

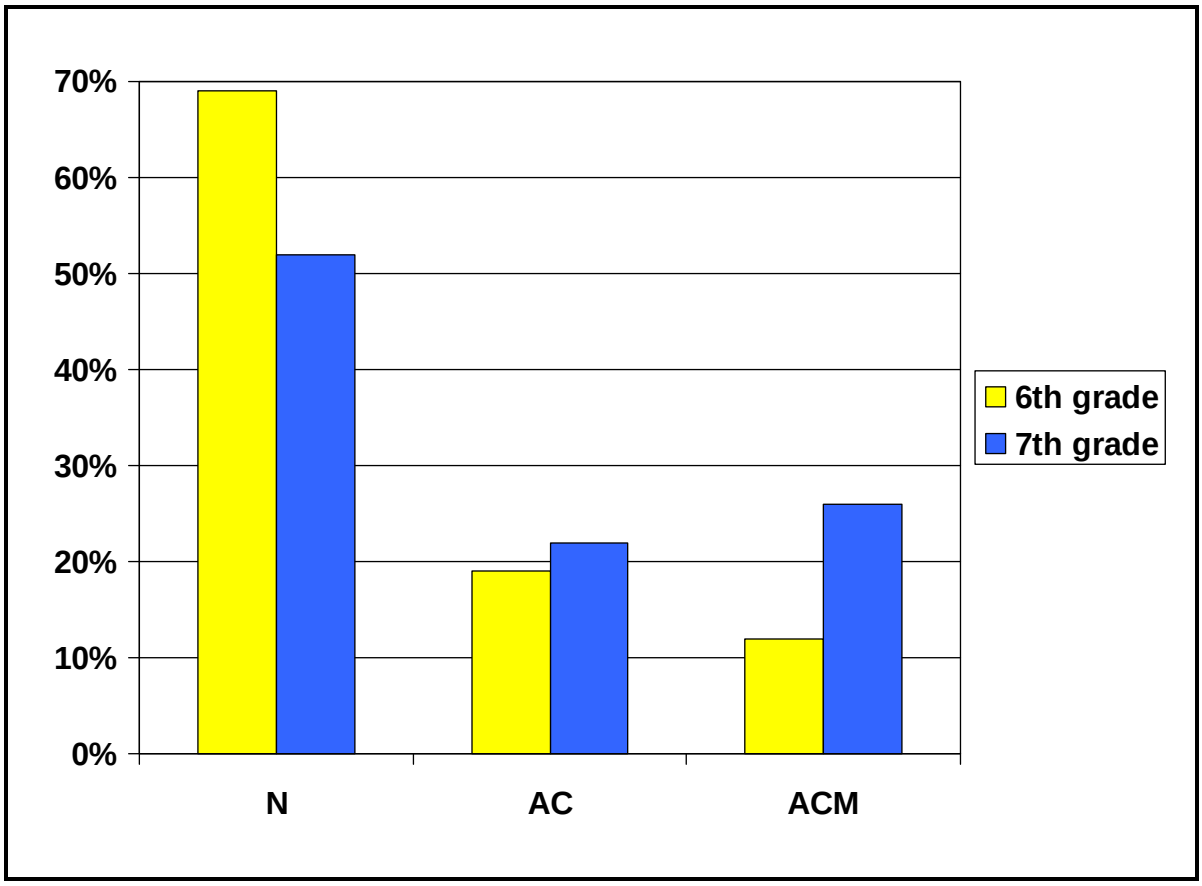
Most of the parameter estimates are near 0 and 1, indicating that the latent variable "substance use" is being measured accurately. For instance, the probability of responding "yes" to the alcohol item given membership in one of the two alcohol use stages is .77 (95% CI: .69, .83). This estimate is lower than estimates for the alcohol item found in the other samples but is still indicative of positive measurement. The probability of responding "yes" to the inhalant item, despite the fact that none of the latent stages include inhalants, is .13—larger than similar estimates from the other samples and indicative of the measurement error associated with the fact that respondents who responded "yes" to the inhalant item are not placed in a latent stage; they are treated as measurement error.

δ parameters: probabilities of latent stage membership. Table 5.36 presents the estimated proportion of adolescents in each of the four latent substance use stages in 6th and 7th grades. These estimates are illustrated in Figure 5.9. In 6th grade, nearly 70% of the African American males in the sample are expected to be in the "no use" latent stage. Membership in the AC stage is more prevalent than in the ACM stage in 6th grade, but this is reversed in 7th grade when 26% are estimated to be in the ACM stage and 22% in the AC stage.

Table 5.36 Final δ Parameter Estimates for Three-Stage Model, African American Males, 6th–7th Grade

Latent Stage	6th Grade	7th Grade
No use	.69	.52
Alcohol + cigarettes	.19	.22
Alcohol + cigarettes + marijuana	.12	.26

Figure 5.9 Overall Prevalence of Substance Use Stages, African American Males, 6th–7th Grade



τ parameters: transition probabilities. The τ parameters express the probability of transitioning from one latent stage to another between grade 6 and grade 7. The τ matrix is presented in Table 5.37.

Table 5.37 τ Parameter Estimates, African American Males, 6th–7th Grade

Latent Stage in 6th Grade	Latent Stage in 7th Grade			Advance Rate
	N	AC	ACM	
No use (N)	.745	.160	.095	.255
	(.63, .79)	(.05, .16)	(.03, .13)	
Alcohol + cigarettes (AC)	—	.569	.431	.431
		(.39, .73)	(.27, .61)	
Alcohol + cigarettes + marijuana (ACM)	—	—	1.0	
Overall advance rate				.259

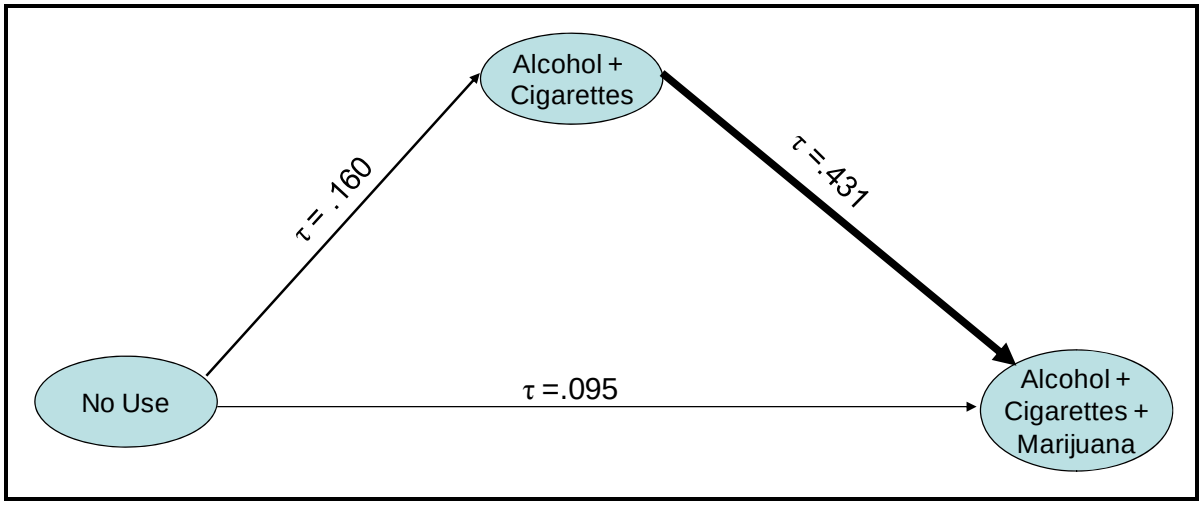
Notes: The τ parameter estimates represent the probability of transitioning to the column "latent stage in 7th grade," conditional on membership in the row "latent stage in 6th grade."

Dash (—) indicates that parameter was fixed to zero to represent the onset model.

Point estimate and 95% confidence intervals based on data augmentation.

An estimated 74.5% of African American males remain in the "no use" stage between 6th and 7th grade. Among those who transition out, 16% transition to the AC stage and 9.5% transition to the ACM stage. The transition probability from AC in 6th grade to ACM in 7th grade is very large: 43% of those in the AC stage in 6th grade are estimated to transition to marijuana use by the 7th grade.

Figure 5.10 Final Three-Stage Model for African American Males, 6th–7th Grade, with Transitional Probability Estimates



A three-stage model was stable and provided a good overall fit (G^2 value less than the degrees of freedom) for African American males transitioning from 6th to 7th grade. This model does not include any stages where inhalant is present, suggesting that the gateway drug use sequence cannot be extended to include inhalants for this group.

5.2.3.2 7th–8th Grade Transition

Table 5.38 presents goodness-of-fit measures for various LTA models for African American males transitioning from 7th to 8th grade. Unlike the 6th–7th grade sample, all of the G^2 values are larger than the degrees of freedom, evidence that none of the models appear to fit the data especially well. A seven-stage model was estimated, but a review of the ρ parameters suggested that two of the seven latent stages were redundant, so it is excluded. The stages present in the four-, five-, and six-stage models are very similar to those identified for African American males in the 6th–7th grade sample.

Table 5.38 Goodness-of-Fit for Various Models, African American Males, 7th–8th Grade

Model[a]	G^2 (df)	AIC	BIC	Cross-validation G^2_a	Cross-validation G^2_b
4 (N, AC, CM, ACM)	379.84 (231)	427.84	537.17	279.615	301.432
5 (N, AC, CM, ACM, ACIM)	324.89 (222)	390.89	541.21	306.824	305.015
6 (N, A, AC, CM, ACM, ACIM)	268.00 (213)	352.00	543.32	238.503	276.855

Notes: A = alcohol only, AC = alcohol + cigarettes, ACIM = alcohol + cigarettes + inhalants + marijuana; ACM = alcohol + cigarettes + marijuana; N = no use.

N = 703.

Model labels are based on the ρ parameters for the model.

Seven-stage model included two redundant latent stages (only six unique latent stages).

The AIC and BIC estimates designate different models as having the best model fit, with AIC favoring the six-stage model and BIC favoring the four-stage model. Cross-

validation results support the six-stage model, as it has the lowest cross-validation G^2 for both random samples.

The ρ parameters for each model were examined to determine how well the latent stages are measured. In these baseline models, measurement is unconstrained: the ρ parameters are freely estimated (although the parameter estimates are held constant for both periods). Initial LTA estimates for the four-, five-, and six-stage models indicate generally strong measurement of the latent stages, with measurement for the six-stage model appearing to be the strongest; each of the stages is clearly distinguishable, and the ρ estimates are all close to 0 and 1. For the six-stage model, the probability of responding "yes" to each of the four drug use items, given membership in one of the four stages, is presented in Table 5.39.

Table 5.39 Freely Estimated ρ Parameters for Response "Yes," Six-Stage Model, African American Males, 7th–8th Grade

	Latent Stage					
Item	**No Use**	**Alcohol**	**Alcohol + Cigarettes**	**Cigarettes + Marijuana**	**Alcohol + Cigarettes + Marijuana**	**Alcohol + Cigarettes + Inhalants + Marijuana**
Ever used alcohol	.08	**.83**	**.72**	.36	**1.00**	**.80**
Ever used cigarettes	.06	.14	**.95**	**.58**	**.96**	**.87**
Ever used inhalants	.01	.20	.03	.23	.10	**1.00**
Ever used marijuana	.00	.08	.00	**.80**	**.92**	**.65**

Note: ρ parameters are constrained equal for both time points, so the estimates are the same for both grades.

When the six-stage model was analyzed using DA (with 100 imputations), the ρ (Rho) parameter estimates and identified stages were consistent across imputations. Given that the six-stage model appears to have the best relative fit (based on the AIC, and the two cross-validation G^2s) and because the measurement appears to be strong and consistent, it was selected as the final model for African American males transitioning from 7th to 8th grade. The stages represent "no drug use" (N), "alcohol only" (A), "alcohol + cigarettes"

(AC), “cigarettes + marijuana (CM), “alcohol + cigarettes + marijuana” (ACM), and “alcohol + cigarettes + inhalants + marijuana” (ACIM).

These preliminary results suggest a relatively important role for marijuana in this sample. The presence of the CM stage, hinted at for the 6th–7th grade sample and confirmed here, is not a typical stage described in the literature on the gateway hypothesis and is an important distinction between this sample and the other race/gender samples. Unlike the 6th–7th grade sample, there is evidence to suggest that the gateway model for African American males in 7th–8th grade can be expanded to include inhalants (based on the presence of an ACIM stage); but there is no evidence to suggest that inhalant use precedes, or is a gateway to, alcohol, cigarette, or marijuana use for African American males in the 7th–8th grade transition period.

Parameter Constraints for the Final Model. To obtain final parameter estimates for the six-stage model and to ensure model identification, constraints were placed on the measurement (ρ) and transition (τ) matrices. Table 5.40 presents the constraints placed on the ρ parameters, and Table 5.41 presents the parameter constraints for the τ matrix.

Table 5.40 Constraints on ρ Parameters for African American Males, 7th–8th Grade

		Drug Use Item			
	Latent Stage	Ever Tried Alcohol	Ever Tried Cigarettes	Ever Tried Inhalants	Ever Tried Marijuana
Probability of responding "no" given latent stage membership	No use	2	7	11	15
	A	5	7	11	15
	AC	5	9	11	15
	CM	2	9	11	17
	ACM	5	9	11	17
	ACIM	5	9	13	17
Probability of responding "yes" given latent stage membership	No use	4	8	12	16
	A	6	8	12	16
	AC	6	10	12	16
	CM	4	10	12	18
	ACM	6	10	12	18
	ACIM	6	10	14	18

Notes: A = alcohol; AC = alcohol + cigarettes; ACM = alcohol + cigarettes + marijuana; ACM = alcohol + cigarettes + inhalants + marijuana; CM = cigarettes + marijuana.

Each unique number is freely estimated. Same numbers are constrained to be equal. For instance, the probability of responding "yes" to the alcohol ever use item given membership in any of the A, AC, ACM, or ACIM latent stages is constrained to be equal. This constraint ensures that the meaning of the alcohol use item is held constant across latent stages. Estimates are also constrained to be equal for both time points (measurement invariance).

Table 5.41 Constraints on τ Parameters for African American Males, 7th–8th Grade

	No Use	A	AC	CM	ACM	ACIM
No use	FR	FR	FR	FR	FR	FR
A	0	FR	FR	0	FR	FR
AC	0	0	FR	0	FR	FR
CM	0	0	0	FR	FR	FR
ACM	0	0	0	0	FR	FR
ACIM	0	0	0	0	0	FR

Notes: A = alcohol; AC = alcohol + cigarettes; ACM = alcohol + cigarettes + marijuana; ACM = alcohol + cigarettes + inhalants + marijuana; CM = cigarettes + marijuana; 0 = fixed to zero (not estimated).

To ensure that the final model, with the applied constraints, is the proper solution for the six-stage model, the model was analyzed 100 separate times, using random start values. The originally identified six-stage model was the most frequently obtained result, with 42 out of 100 analyses producing the same result. There were four alternate solutions. The original

solution did not have the lowest (best) G^2 (612.29). An alternate model with just four stages (N, A, C, AC) had a lower G^2 (599.69) and was the solution 30 times. There is significant inconsistency in this model, as evidenced by the fact that fewer than 50% of the models converged to the original solution, an alternate model had a lower G^2, and there were four alternate models estimated. Although as the most commonly derived model (and the model most consistent with the study hypotheses) the six-stage model is selected, interpretation of the results should be particularly cautious given these findings.

The assumption of measurement invariance was tested via a χ^2 difference test for the difference between the model with the ρ parameters constrained to be equal (invariant) for both time points (G^2 = 383.934, 229 *df*) and the model without the measurement invariance constraint (G^2 = 367.57, 221 *df*). The difference of 16.364, with 8 degrees of freedom, is significant (p = .0375), suggesting that the measurement invariance constraint is not supported by the data. However, although the ρ parameter estimates are generally weaker (closer to .50) in 8th grade, the same six stages are still interpretable. The measurement invariance constraint aids the interpretation of the results, so despite evidence that this assumption may be violated, the constrained model is retained.

Final model results, African American males, 7th–8th grade.

ρ parameters (model measurement). The final ρ parameter estimates and 95% confidence intervals are presented in Table 5.42. Overall measurement is modestly strong—all of the estimates are near .80, indicating that latent stage membership is predictive of responses to the drug use items.

Table 5.42 Final ρ Parameter Estimates for Response "Yes," Six-Stage Model, African American Males, 7th–8th Grade

	Latent Stage					
Item	**No Use**	**Alcohol**	**Alcohol + Cigarettes**	**Cigarettes + Marijuana**	**Alcohol + Cigarettes+ Marijuana**	**Alcohol + Cigarettes + Inhalants + Marijuana**
Ever used alcohol	.07 (.03, .12)	**.79 (.74, .84)**	**.79 (.74, .84)**	.07 (.03, .12)	**.79 (.74, .84)**	**.79 (.74, .84)**
Ever used cigarettes	.07 (.05, .12)	.07 (.05, .12)	**.82 (.78, .86)**	**.82 (.78, .86)**	**.82 (.78, .86)**	**.82 (.78, .86)**
Ever used inhalants	.05 (.03, .07)	.05 (.03, .07)	.05 (.03, .07)	.05 (.03, .07)	.05 (.03, .07)	**.77 (.61, .70)**
Ever used marijuana	.02 (.01, .05)	.02 (.01, .05)	.02 (.01, .05)	**.78 (.70, .84)**	**.78 (.70, .84)**	**.78 (.70, .84)**

Note: Point estimates and 95% confidence intervals based on data augmentation.

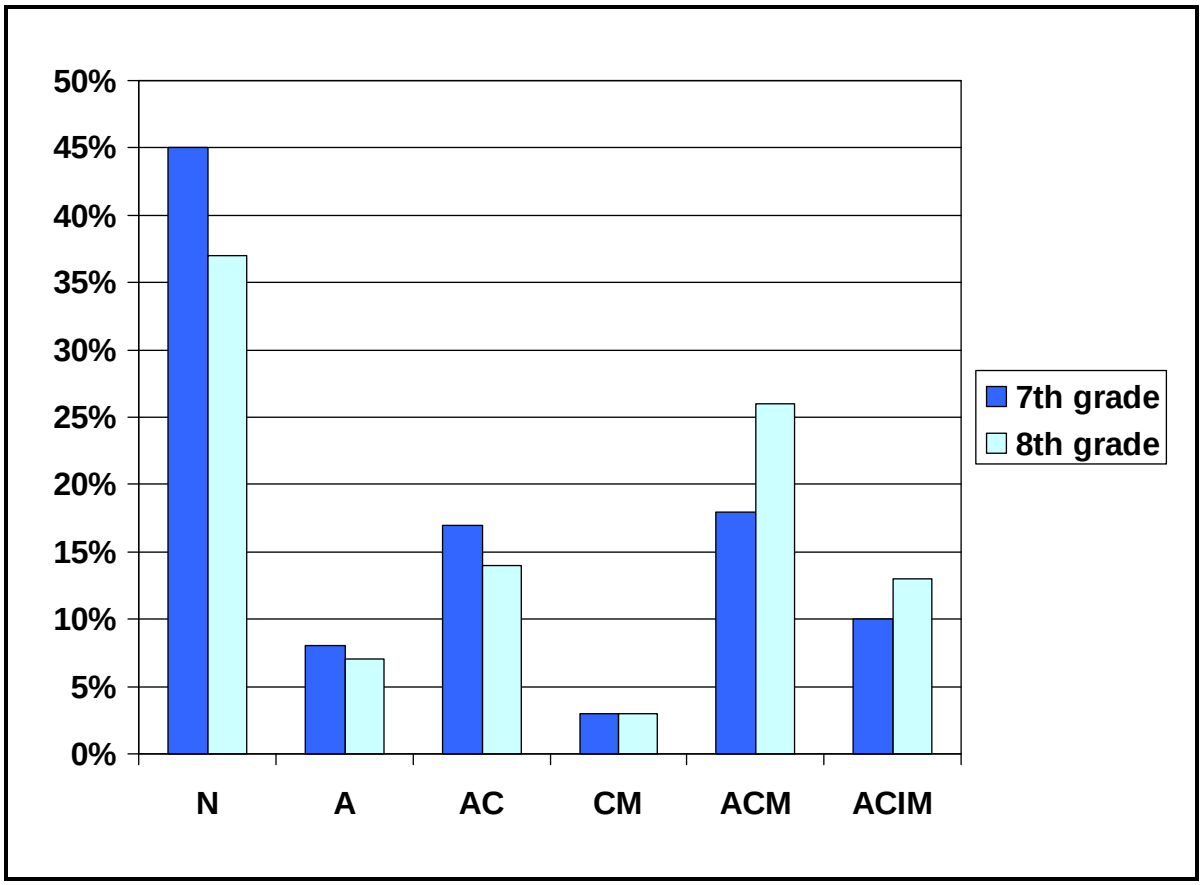
δ parameters: probabilities of latent stage membership. Table 5.43 and Figure 5.11 show the estimated proportion of African American male adolescents in each of the six latent substance use stages in 7th and 8th grades. Notable is the finding that prevalence for the "Alcohol + Cigarettes + Marijuana" (ACM) stage is second only to the "no use" stage in 7th and 8th grades. By 8th grade, 26% of the sample is expected to be in the ACM stage.

Table 5.43 Final δ Parameter Estimates for Six-Stage Model, African American Males, 7th–8th Grade

Latent Stage	7th Grade	8th Grade
No use	.45	.37
Alcohol	.08	.07
Alcohol + cigarettes	.17	.14
Cigarettes + marijuana	.03	.03
Alcohol + cigarettes + marijuana	.18	.26
Alcohol + cigarettes + inhalants + marijuana	.10	.13

Note: Values do not sum to 1 due to rounding error.

Figure 5.11 Overall Prevalence of Substance Use Stages, African American Males, 7th–8th Grade



τ parameters: transition probabilities. The τ parameters express the probability of transitioning from one latent stage to another between grade 7 and grade 8. The τ matrix is presented in Table 5.44, and the final six-stage model is presented in Figure 5.12. In general, transitioning to a more advanced stage is rare in this sample: 84.7% remain in the same stage from 7th to 8th grade. Respondents in the "Alcohol + Cigarettes" stage in 7th grade appear to be substantially more likely than others to transition to a more advanced stage by 8th grade; 22.9% transition to the ACM stage. Very few African American males in this sample transition to inhalant use (ACIM).

Table 5.44 τ Parameter Estimates, African American Males, 7th–8th Grade

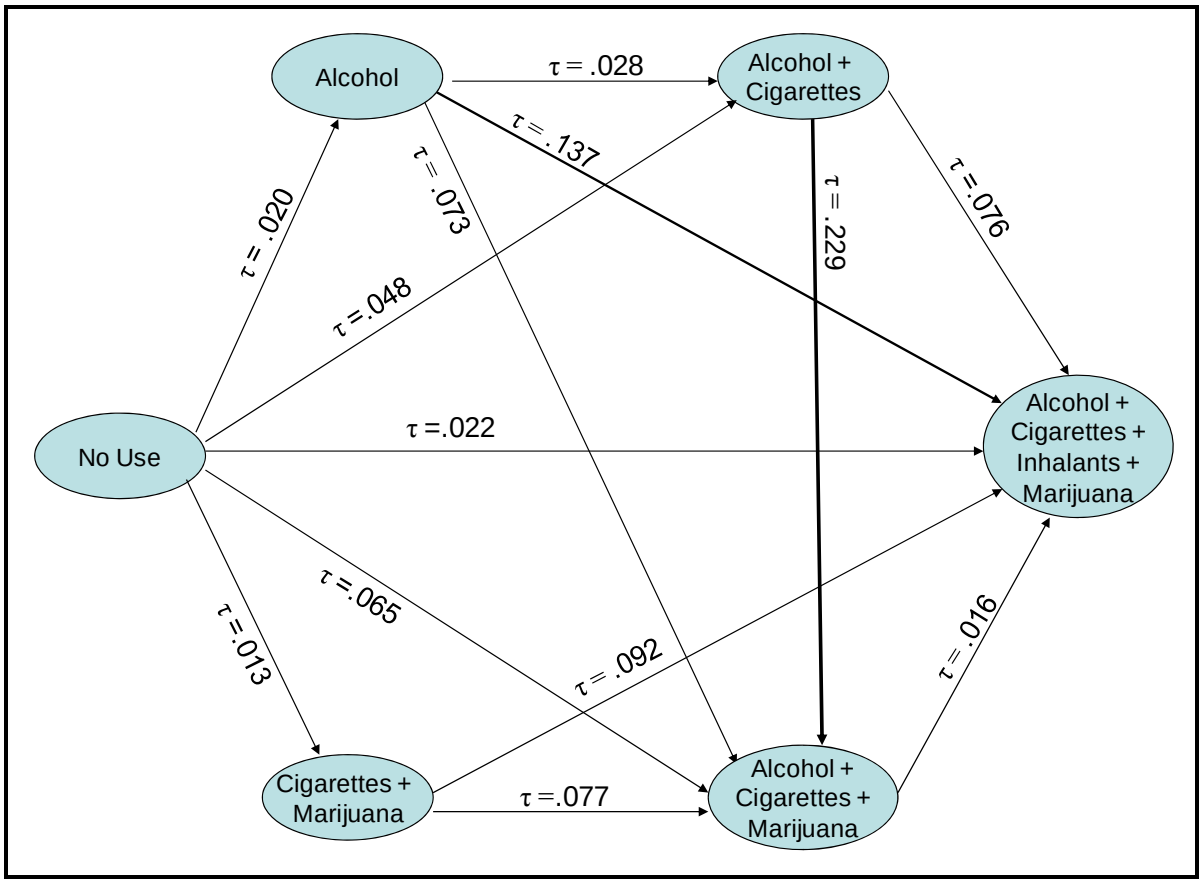
Latent Stage in 7th Grade	Latent Stage in 8th Grade						Advance Rate
	N	A	AC	CM	ACM	ACIM	
No use (N)	.832 (.76, .89)	.020 (.00, .17)	.048 (.01, .17)	.013 (.00, .11)	.065 (.02, .16)	.022 (.00, .14)	.168
Alcohol (A)	—	.762 (.47, .93)	.028 (.00, .25)	—	.073 (.00, .46)	.137 (.01, .56)	.238
Alcohol + cigarettes (AC)	—	—	.695 (.49, .85)	—	.229 (.05, .57)	.076 (.00, .41)	.305
Cigarettes + marijuana (CM)	—	—	—	.831 (.34, .99)	.077 (.00, .54)	.092 (.00, .57)	.169
Alcohol + cigarettes + marijuana (ACM)	—	—	—	—	.984 (.86, 1.00)	.016 (.00, .14)	.016
Alcohol + cigarettes + inhalants + marijuana (ACIM)	—	—		—	—	1.00	
Overall advance rate							.153

Notes: The τ parameter estimates represent the probability of transitioning to the column "latent stage in 8th grade," conditional on membership in the row "latent stage in 7th grade."

Dash (—) indicates that parameter was fixed to zero to represent the onset model.

Point estimates and 95% confidence intervals based on data augmentation.

Figure 5.12 Final Six-Stage Model for African American Males, 7th–8th Grade, with Transitional Probability Estimates



Unlike the results for the 6th to 7th grade transition, for African American males transitioning from 7th to 8th grade, there is evidence to suggest that the gateway drug use sequence can be extended to include inhalants. The lone stage including inhalants (ACIM) suggests that, for this sample, inhalant use only occurs in conjunction with other gateway drug use. There is no evidence that inhalant use precedes marijuana use (Hypothesis 1.1) or by extension that inhalants serve as a partial gateway to marijuana use (Hypothesis 1.2).

5.2.4 African American Females

5.2.4.1 6th–7th Grade Transition

Table 5.45 presents goodness-of-fit measures for various LTA models for African American females transitioning from 6th to 7th grade. All of the models have G^2 values that are less than the degrees of freedom, suggesting a good overall fit. In this case, all of the models appear to fit the data well. The AIC favors the six-stage model, whereas the BIC and both cross-validation G^2s clearly favor the four-stage model. Based on these results, the four-stage model appears to provide the best combination of fit and parsimony.

Table 5.45 Goodness-of-Fit for Various Models, African American Females, 6th–7th Grade

Model[a]	G^2 (df)	AIC	BIC	Cross-validation G^2_a	Cross-validation G^2_b
4 (N, A, C, AC)	134.55 (231)	182.55	274.37	182.627	139.174
5 (N, A, C, AC, ACM)	118.74 (222)	184.74	310.99	289.214	149.168
6 (N, A, C, AC, AI, ACM)	101.23 (216)	179.23	328.44	203.691	167.056
7 (N, A, C, AC, AI, CI, ACM)	89.74 (210)	179.74	351.91	577.627	157.919

Notes: A = alcohol; AC = alcohol + cigarettes; ACIM = alcohol + cigarettes + inhalants + marijuana; ACM = alcohol + cigarettes + marijuana; AI = alcohol + inhalants; C = cigarettes; CI = cigarettes + inhalants; N = no use.

N = 339.

Model labels are based on the ρ parameters for the model.

For the four-stage model, the probability of responding "yes" to each of the four drug use items, given membership in one of the four stages, is presented in Table 5.46. The latent stage labels are based on the pattern of ρ estimates.

Table 5.46 Freely Estimated ρ Parameters for Response "Yes," Four-Stage Model, African American Females, 6th–7th Grade

	Latent Stage			
Item	**No Use**	**Alcohol**	**Cigarettes**	**Alcohol + Cigarettes**
Ever used alcohol	.00	**.66**	.32	**1.00**
Ever used cigarettes	.01	.09	**1.00**	**1.00**
Ever used inhalants	.03	.11	.19	.27
Ever used marijuana	.01	.05	.17	.35

Note: ρ parameters are constrained equal for both time points, so the estimates are the same for both grades.

When each of the models was analyzed using DA (with 100 imputations), additional support for the four-stage model emerged. The ρ (Rho) parameter estimates for the four-stage model suggest that the measurement of the four latent stages is consistent across imputations —that is, the same four stages are present and the measurement quality is similar to that obtained in the original LTA—while the more complex models were unstable across the imputed data sets. In fact, for each (five, six, and seven latent stages) model, the same four stages are the only ones that remain identifiable across the imputed data sets. Based on this collection of evidence, for African American females transitioning from 6th to 7th grade, the four-stage model was selected as the final model. The stages represent "no drug use" (N), "alcohol only" (A), "alcohol + cigarettes" (AC), and "alcohol + cigarettes + inhalants + marijuana" (ACIM).

These preliminary results suggest that for African American females transitioning from 6th to 7th grade, only stages including alcohol and cigarettes are present. Given that the basic frequencies of use for these two substances (see Table 4.4) clearly indicate that these substances are used by nontrivial numbers of African American females, it is likely that the failure to identify a stable model that includes the use of these drugs reflects inconsistency in reporting or insufficient sample size/power to detect them.

Parameter constraints for the final model. To obtain final parameter estimates for the four-stage model and to ensure model identification, constraints were placed on the measurement (ρ) and transition (τ) matrices. Table 5.47 illustrates the constraints placed on the ρ parameters, and Table 5.48 illustrates the constraints placed on the τ matrix.

Table 5.47 Constraints on *ρ* Parameters for African American Females, 6th–7th Grade

		Drug-Use Item			
	Latent Stage	Ever Tried Alcohol	Ever Tried Cigarettes	Ever Tried Inhalants	Ever Tried Marijuana
Probability of responding "no" given latent stage membership	No use	2	7	11	15
	A	5	7	11	15
	C	2	9	11	15
	AC	5	9	11	15
Probability of responding "yes" given latent stage membership	No use	4	8	12	16
	A	6	8	12	16
	C	4	10	12	16
	AC	6	10	12	16

Note: A = alcohol; AC = alcohol + cigarettes; C = cigarettes.

Each unique number is freely estimated. Same numbers are constrained to be equal. For instance, the probability of responding "yes" to the alcohol ever use item given membership in either the A or AC latent stage is constrained to be equal. This constraint ensures that the meaning of the alcohol use item is held constant across latent stages. Estimates are also constrained to be equal for both time points (measurement invariance).

Table 5.48 Constraints on *τ* Parameters for African American Females, 6th–7th Grade

	No Use	A	C	AC
No use	FR	FR	FR	FR
A	0	FR	0	FR
C	0	0	FR	FR
AC	0	0	0	FR

Notes: A = alcohol; AC = alcohol + cigarettes; C = cigarettes; FR = freely estimated.
0 = fixed to zero (not estimated).

To ensure that the final model, with the applied constraints, is the proper solution for the four-class model, the model was analyzed 100 separate times, using random start values. The identical four stages were identified for all 100 solutions. However, the order of the

stages (the transition matrix) differed, with four different solutions. The original model, based on the gateway hypothesis, assumes that no "backward" movement is allowed. Three of the solutions included backward movement (for instance, from alcohol use to no use). However, because these three alternate models are conceptually impossible for an onset model, the original model is selected as the final model.

The assumption of measurement invariance was tested via a χ^2 difference test for the difference between the model with the ρ parameters constrained to be equal (invariant) for both time points (G^2 = 302.679, 241 *df*) and the model without the measurement invariance constraint (G^2 = 264.724, 235 *df*). The difference of 37.955, with 6 degrees of freedom, is significant ($p < .0001$), indicating that the measurement invariance assumption is not supported by the data. However, the same four stages are present and well-measured at both time points. To facilitate interpretation, measurement invariance is assumed for the final model, with the caveat that relaxing this constraint would improve the fit of the model.

Final model results, African American females, 6th–7th grade. To obtain final parameter estimates and standard errors, DA was conducted. DA was applied to the final constrained model, and the results were combined to generate final parameter estimates that take into account the uncertainty present across the imputed data sets.

ρ parameters (model measurement). The final ρ parameter estimates, specifically the probability of responding "yes" to each item, along with 95% confidence intervals, are presented in Table 5.49. The values were constrained to be equal across time (measurement invariance), so the ρ parameters are the same for both time points. To achieve identification and model stability by reducing the number of parameters estimated, additional constraints were imposed such that only two parameters are estimated for each item. The probability of

responding "no" can be obtained by subtracting the parameters in Table 5.49 from 1.00. The probabilities for "yes" responses to both the alcohol and cigarette use items, given membership in one of the latent stages, are quite high (.91–.93).

Table 5.49 Final ρ Parameter Estimates for Response "Yes," Four-Stage Model, African American Females, 6th–7th Grade

	Latent Stage			
Item	**No Use**	**Alcohol**	**Cigarettes**	**Alcohol + Cigarettes**
Ever used alcohol	.09 (.05, .17)	**.91 (.82, .97)**	.09 (.05, .17)	**.91 (.82, .97)**
Ever used cigarettes	.03 (.01, .08)	.03 (.01, .08)	**.93 (.80, .99)**	**.93 (.80, .99)**
Ever used inhalants	.13 (.10, .15)	.13 (.10, .15)	.13 (.10, .15)	.13 (.10, .15)
Ever used marijuana	.12 (.10, .15)	.12 (.10, .15)	.12 (.10, .15)	.12 (.10, .15)

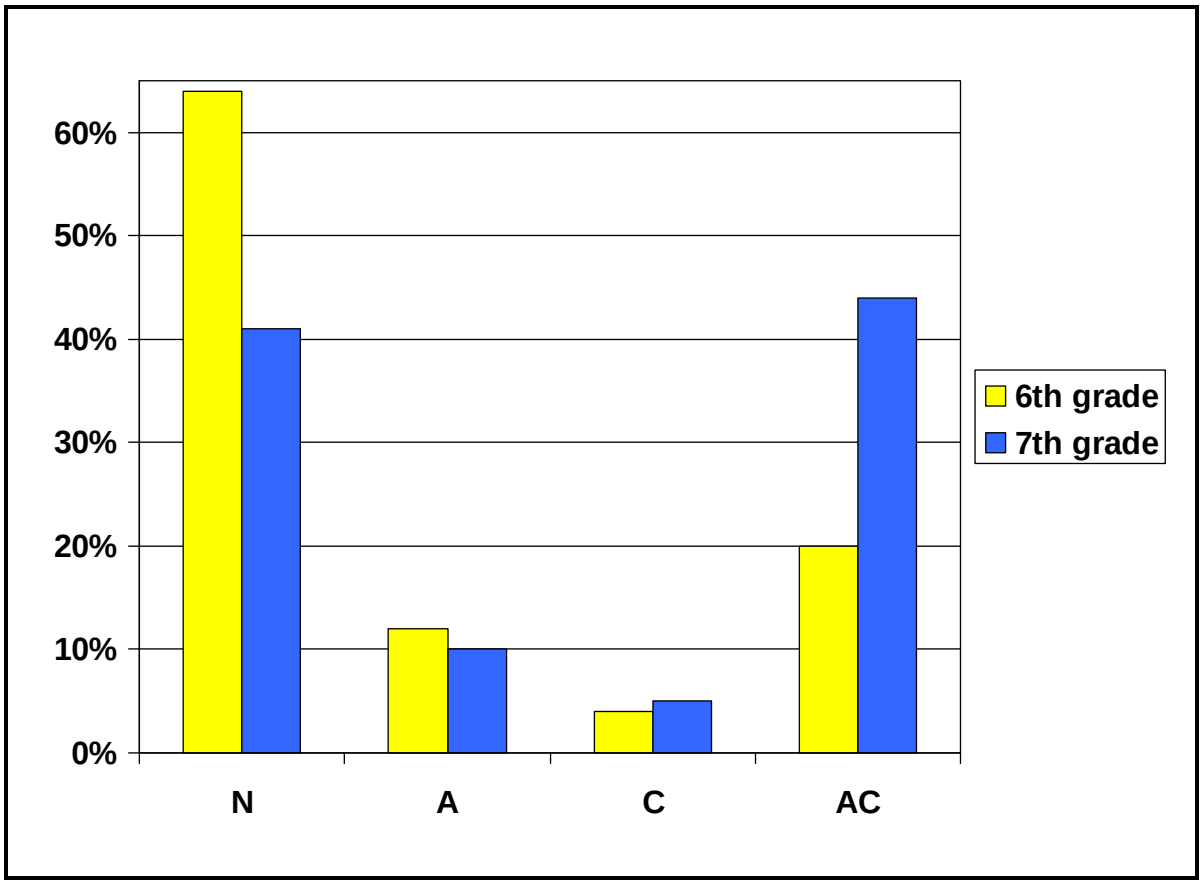
Note: Point estimate and 95% confidence intervals based on data augmentation.

δ parameters: probabilities of latent stage membership. δ parameters representing the probability of being in a certain latent stage at each grade are presented in Table 5.50 and illustrated in Figure 5.13. Prevalence for the "no use" stage (64%) was substantially greater than for the other latent stages in grade 6. By 7th grade, the prevalence for the "alcohol + cigarettes" stage is highest (44%).

Table 5.50 Final δ Parameter Estimates for Four-Stage Model, African American Females, 6th–7th Grade

Latent Stage	6th Grade	7th Grade
No use	.64	.41
Alcohol	.12	.10
Cigarettes	.04	.05
Alcohol + cigarettes	.20	.44

Figure 5.13 Overall Prevalence of Substance Use Stages, African American Females, 6th–7th Grade



τ parameters: transition probabilities. The τ parameters express the probability of transitioning from one latent stage to another between grade 6 and grade 7. The τ matrix is presented in Table 5.51, with the final model illustrated in Figure 5.14. Individuals in the "No Use" stage in 6th grade have a .251 probability of transitioning directly to the "Alcohol and Cigarettes" (AC) stage in 7th grade. Those in the "Alcohol only" (A) stage in 6th grade were more likely to transition to the AC stage (.552) than to remain in the same stage.

Table 5.51 τ Parameter Estimates, African American Females, 6th–7th Grade

Latent Stage in 6th Grade	Latent Stage in 7th Grade				Advance Rate
	N	A	C	AC	
No use (N)	.646 (.55, .74)	.080 (.01, .30)	.023 (.00, .17)	.251 (.18, .34)	.354
Alcohol (A)	—	.448 (.23, .68)	—	.552 (.32, .77)	.552
Cigarettes (C)	—	—	.866 (.33, .99)	.134 (.01, .67)	.134
Alcohol + cigarettes (AC)	—	—	—	1.0	
Overall advance rate					.299

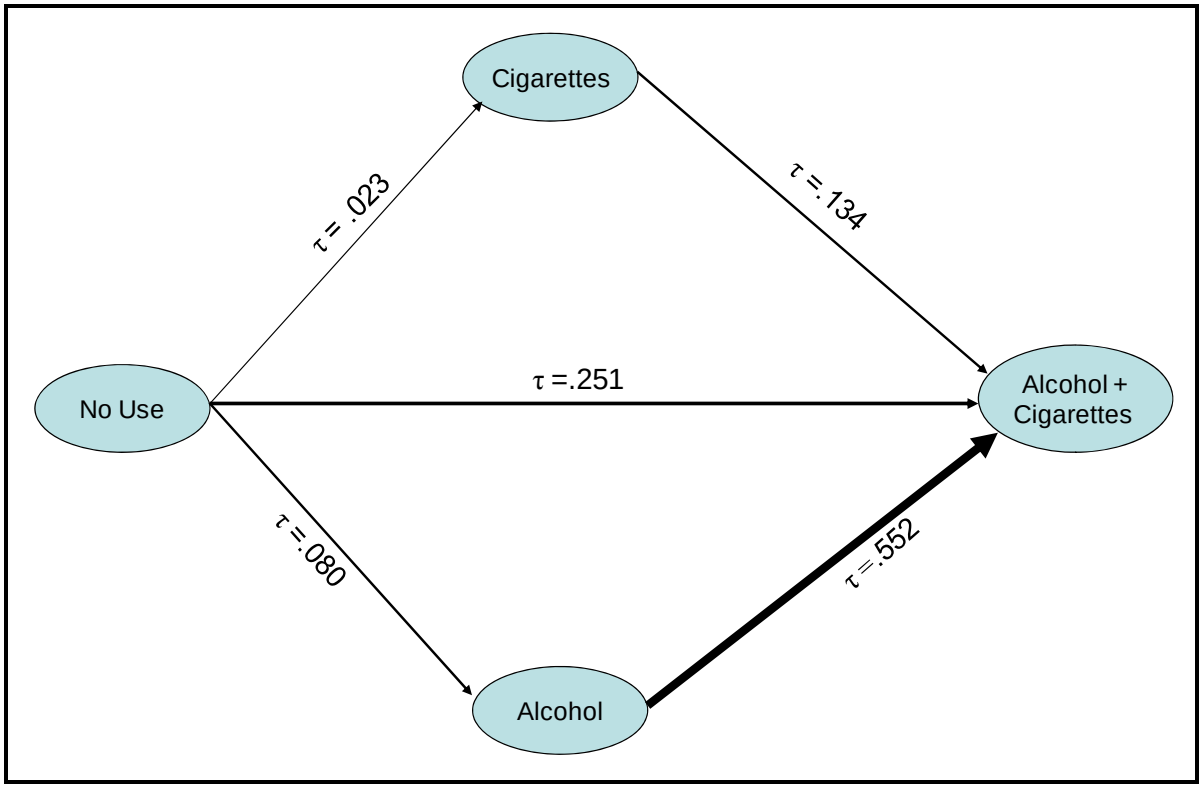
Notes: A = alcohol, AC = alcohol + cigarettes; C = cigarettes; N = no use.

The τ parameter estimates represent the probability of transitioning to the column "latent stage in 7th grade," conditional on membership in the row "latent stage in 6th grade."

Dash (—) indicates that parameter was fixed to zero to represent the onset model.

Point estimate and 95% confidence intervals based on data augmentation.

Figure 5.14 Final Four-Stage Model for African American Females, 6th–7th Grade, with Transitional Probability Estimates



As with African American males in the 6th to 7th grade transition, based on these results, there is no evidence that the gateway hypothesis can be extended to include inhalants for African American females. The final four-stage model did not include any stages with inhalants; therefore, for this population, there is no evidence to support the study hypotheses regarding inhalants.

5.2.4.2 7th–8th Grade Transition

Table 5.52 provides goodness-of-fit measures for various LTA models for African American females transitioning from 7th to 8th grade. Based on the initial results, it appeared that the five- or six-stage model provided the best fit for the data. The five-stage model had the lowest BIC, whereas the six-stage model had the lowest AIC and G^2 on one of the cross-validation samples. Unlike the 6th–7th grade African American female sample, it appears that both inhalants and marijuana are included in the drug use sequence for this sample. However, the results were unstable (as described below), and an alternate four-stage model was required. This alternate model is similar to the model identified for the 6th–7th grade transition period for African American females, with the addition of marijuana and the exclusion of a cigarettes-only stage.

Table 5.52 Goodness-of-Fit for Various Models, African American Females, 7th–8th Grade

Model[a]	G^2 (df)	AIC	BIC	Cross-validation G^2_a	Cross-validation G^2_b
4 (N, AC, AI, ACM)	293.77 (232)	339.77	445.47	235.131	254.046
4[b] (N, A, AC, ACM)	285.59 (230)	335.59	450.49	c	c
5 (N, A, AC, AI, ACM)	233.85 (224)	295.85	438.32	230.825	244.051
6 (N, A, C, I, AC, ACM)	208.00 (216)	286.00	465.24	192.890	242.112
7 (N, A, C, I, AC, ACI, ACM)	191.52 (210)	289.52	514.71	238.770	227.180

[a] Model labels are based on the ρ parameters for the model.

[b] During model validation, the models originally identified were unstable. This alternate four-stage model (N, A, AC, ACM) was the only model that remained stable across 100 random validation samples. When four-, five-, six-, or seven-stage models were estimated with random start values, interpretation of the ρ values identified this alternate four-stage model.

[c] Cross-validation was not performed on this model, as it is the only model that provides stable measurement for this subsample.

N = 732.

Notes: A = alcohol; AC = alcohol + cigarettes; ACIM = alcohol + cigarettes + inhalants + marijuana; ACM = alcohol + cigarettes + marijuana; AI = alcohol + inhalants; C = cigarettes; CI = cigarettes + inhalants; I = inhalants; N = no use.

Each of the models was analyzed using DA (with 100 imputations) to determine whether the models are stable. The results indicated that, regardless of the number of stages included, only four stages were clearly and consistently identifiable based on the ρ parameter estimates. The freely estimated (unconstrained) ρ parameters for this alternate model are presented in Table 5.53.

Table 5.53 Freely Estimated ρ Parameters for Response "Yes," Four-Stage Model, African American Females, 7th–8th Grade

	Latent Stage			
Item	No Use	Alcohol	Alcohol + Cigarettes	Alcohol + Cigarettes + Marijuana
Ever used alcohol	.02	**.88**	**.82**	**.91**
Ever used cigarettes	.04	.00	**.82**	**.95**
Ever used inhalants	.04	.18	.14	.20
Ever used marijuana	.01	.10	.06	**.95**

Note: ρ parameters are constrained equal for both time points, so the estimates are the same for both grades.

Parameter constraints for the final model. To obtain final parameter estimates for the four-stage model and to ensure model identification, constraints were placed on the measurement (ρ) and transition (τ) matrices. Table 5.54 illustrates the constraints placed on the ρ parameters, and Table 5.55 provides the parameter constraints for the τ matrix.

To ensure that the final model, with the applied constraints, is the proper solution for the four-class model, the model was analyzed 100 separate times, using random start values. Two models emerged: the selected four-stage model and an alternate three-stage model (N + C + AC). The four-stage model was the most frequent solution; 61 of the 100 analyses supported the four-stage model. Additionally, the G^2 associated with the four-stage model (583.29) was substantially lower than the G^2 associated with the three-stage model (635.41).

The assumption of measurement invariance was tested via a χ^2 difference test for the difference between the model with the ρ parameters constrained to be equal (invariant) for both time points (G^2 = 349.256, 239 *df*) and the model without the measurement invariance constraint (G^2 = 344.382, 232 *df*). The difference of 4.874, with 7 degrees of freedom, is not significant (p = .8994), supporting the decision to constrain measurement across times.

Table 5.54 Constraints on ρ Parameters for African American Females, 7th–8th Grade

		Drug Use Item			
	Latent Stage	**Ever Tried Alcohol**	**Ever Tried Cigarettes**	**Ever Tried Inhalants**	**Ever Tried Marijuana**
Probability of responding "no" given latent stage membership	No use	2	7	11	15
	A	5	7	11	15
	AC	5	9	11	15
	ACM	5	9	11	17
Probability of responding "yes" given latent stage membership	No use	4	8	12	16
	A	6	8	12	16
	AC	6	10	12	16
	ACM	6	10	12	18

Notes: A = alcohol; AC = alcohol, cigarettes; ACM = alcohol, cigarettes, and marijuana.

Each unique number is freely estimated. Same numbers are constrained to be equal. For instance, the probability of responding "yes" to the alcohol ever use item given membership in either the A, AC, or ACM latent stage is constrained to be equal. This constraint ensures that the meaning of the alcohol use item is held constant across latent stages. Estimates are also constrained to be equal for both time points (measurement invariance).

Table 5.55 Constraints on τ Parameters for African American Females, 7th–8th Grade

	No Use	**A**	**AC**	**ACM**
No use	FR	FR	FR	FR
A	0	FR	FR	FR
AC	0	0	FR	FR
ACM	0	0	0	FR

Notes: A = alcohol; AC = alcohol + cigarettes; ACM = alcohol + cigarettes + marijuana; FR = freely estimated; 0 = fixed to zero (not estimated).

Final model results, African American females, 7th–8th grade. To obtain final parameter estimates and standard errors, DA was conducted on the final constrained model, and the results were combined to generate final parameter estimates that take into account the uncertainty present across the imputed data sets.

ρ parameters (model measurement). The final ρ parameter estimates, specifically the probability of responding "yes" to each item, along with 95% confidence intervals, are

presented in Table 5.56. The values were constrained to be equal across time (measurement invariance), so the ρ parameters are the same for both time points. To achieve identification and model stability, additional constraints were imposed such that only two parameters are estimated for each item; the probability of responding "no" can be obtained by subtracting the parameters in Table 5.56 from 1.00. Most of the parameter estimates are near 0 and 1, indicating that the latent variable "substance use" is being measured accurately.

Table 5.56 Final ρ Parameter Estimates for Response "Yes," Four-Stage Model, African American Females, 7th–8th Grade

	Latent Stage			
Item	**No Use**	**Alcohol**	**Alcohol + Cigarettes**	**Alcohol + Cigarettes + Marijuana**
Ever used alcohol	.03 (.00, .14)	**.87 (.84, .90)**	**.87 (.84, .90)**	**.87 (.84, .90)**
Ever used cigarettes	.08 (.05, .12)	.08 (.05, .12)	**.89 (.85, .92)**	**.89 (.85, .92)**
Ever used inhalants	.13 (.11, .15)	.13 (.11, .15)	.13 (.11, .15)	.13 (.11, .15)
Ever used marijuana	.03 (.01, .05)	.03 (.01, .05)	.03 (.01, .05)	**.87 (.77, .94)**

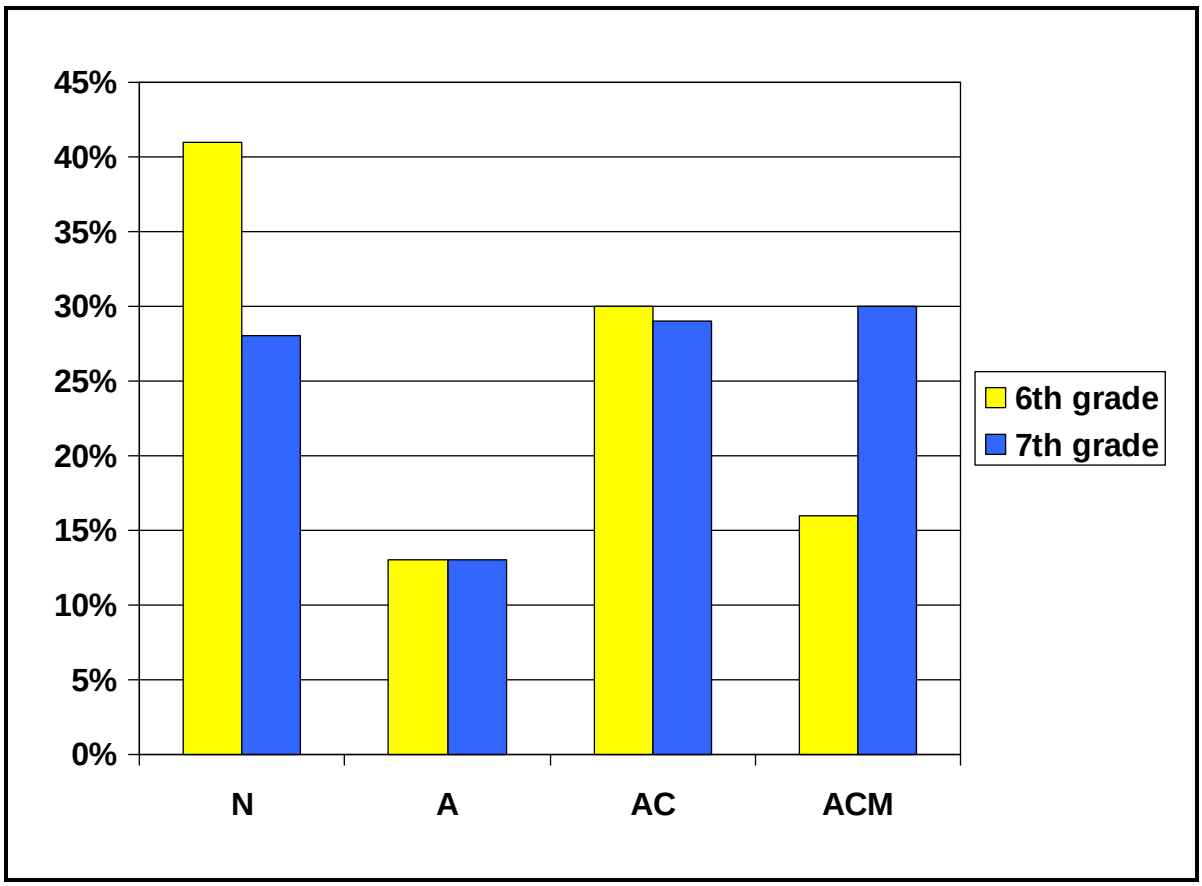
Note: Point estimate and 95% confidence intervals based on data augmentation.

δ parameters: probabilities of latent stage membership. Table 5.57 and Figure 5.15 show the estimated prevalence for each of the four latent substance use stages in 7th and 8th grades. Most notable is the finding that the prevalence in the ACM stage nearly doubles from 7th to 8th grade; by 8th grade, the ACM stage is the most prevalent at 30%.

Table 5.57 Final δ Parameter Estimates for Four-Stage Model, African American Females, 7th–8th Grade

Latent Stage	7th Grade	8th Grade
No use	.41	.28
Alcohol	.13	.13
Alcohol + cigarettes	.30	.29
Alcohol + cigarettes + marijuana	.16	.30

Figure 5.15 Overall Prevalence of Substance Use Stages, African American Females, 7th–8th Grade



τ parameters: transition probabilities. The τ parameters express the probability of transitioning from one latent stage to another between grade 7 and grade 8. The τ matrix is presented in Table 5.58. Membership in either the A or AC latent stage in 7th grade is associated with a relatively strong probability of transitioning to the ACM stage in 8th grade: .217 and .242, respectively. The final model is presented in Figure 5.16.

Consistent with the findings for the 6th to 7th grade transition, there is no evidence to suggest that the gateway hypothesis can be extended to include inhalants for African American females transitioning from 7th to 8th grade. Subsequently, the study hypotheses (1.1 and 1.2) pertaining to the relationship between inhalants and marijuana are not supported here for African American adolescents.

Table 5.58 τ Parameter Estimates, African American Females, 7th–8th Grade

Latent Stage in 7th Grade	Latent Stage in 8th Grade				Advance Rate
	N	A	AC	ACM	
No use (N)	.691 (.55, .74)	.093 (.01, .30)	.125 (.00, .17)	.091 (.18, .34)	.309
Alcohol (A)	—	.704 (.23, .68)	.079 (.00, .46)	.217 (.32, .77)	.296
Alcohol + cigarettes (AC)	—	—	.758 (.33, .99)	.242 (.01, .67)	.242
Alcohol + cigarettes + marijuana (ACM)	—	—	—	1.0	
Overall advance rate					.237

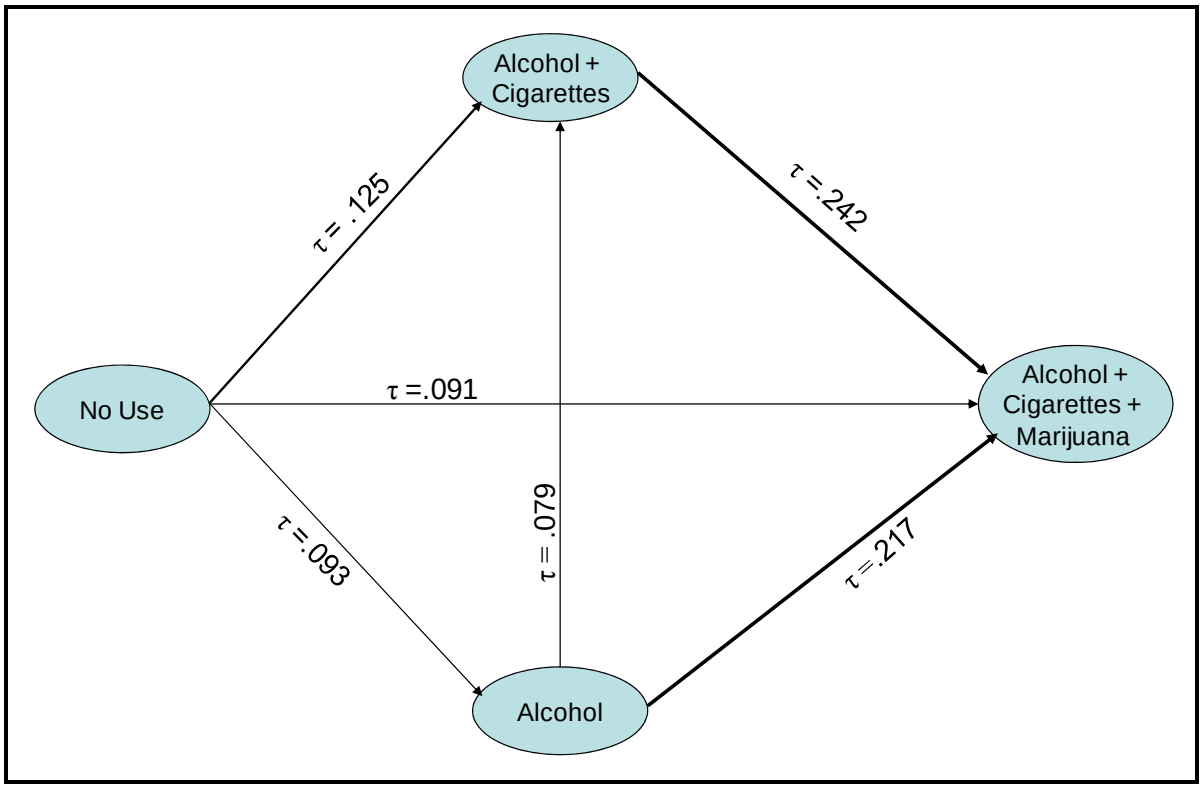
Notes: A = alcohol; AC = alcohol + cigarettes; ACM = alcohol + cigarettes + marijuana.

The τ parameter estimates represent the probability of transitioning to the column "latent stage in 8th grade," conditional on membership in the row "latent stage in 7th grade."

Dash (—) indicates that parameter was fixed to zero to represent the onset model.

Point estimate and 95% confidence intervals based on data augmentation.

Figure 5.16 Final Four-Stage Model for African American Females, 7th–8th Grade, with Transitional Probability Estimates



5.2.5 Summary of Results for Research Question 1

Separate LTA models were identified for each of the race/gender combinations in this study (white males, white females, African American males, and African American females) at two transitions. This provides evidence in support of study Hypothesis 1.3: "drug use sequencing models will differ by race and gender…" It appears that, based on these results, drug use sequencing patterns differ by race and gender for this sample when inhalants are considered as part of the gateway drug use sequence.

The number and type of stages differed by sample, precluding direct comparisons between samples. In general, each of the samples had similar probabilities for membership in the "no use" stage (Table 5.59), although white males in the 6th–7th grade transition period

were significantly less likely to be in the "no use" stage (i.e., they were more likely to have used one or more drugs).

Table 5.59 Prevalence of Membership in the "No Use" Latent Stage (δ) at Baseline for Each Group

	Prevalence of "No Use" Stage Membership at Baseline	
	6th–7th Grade	7th–8th Grade
White males	.486 (.427, .546)	.360 (.320, .401)
White females	.606 (.553, .658)	.410 (.373, .448)
African American males	.692 (.617, .764)	.447 (.396, .499)
African American females	.638 (.566, .709)	.405 (.358, .453)

Note: 95% confidence intervals in parentheses.

Also similar were the overall probabilities of transitioning out of a current stage into a later stage, with the exception of white females. Table 5.60 includes estimates of the overall probability of advancing to a later stage for each of the two transition periods. White females had a higher estimated overall advance rate at both periods, although the disparity is most pronounced for the 6th–7th grade period; 35.7% of white females in this sample moved from one latent stage at 6th grade to a more "advanced" stage by 7th grade.

Table 5.60 Estimated Overall Advance Rate for Each Group

	Overall Advance Rate	
Sample	6th–7th Grade	7th–8th Grade
White males	.267	.200
White females	.357	.253
African American males	.259	.153
African American females	.299	.237

Note: The overall advance rate is an estimate of the overall probability of transitioning from any stage to a later stage.

Models were identified for each of the four samples and for both transition periods. Models that included inhalants were identified for white males and white females at both transition periods and for African American males in the 7th to 8th grade transition period, suggesting that the gateway hypothesis can be extended to include inhalants (Research

Question 1). However, evidence in support of the hypothesis that "inhalant use will precede marijuana use for a significant number of adolescents" (Hypothesis 1.1) was only obtained for white females. For white females, the results suggest that inhalant use at either the 6th or 7th grade increases the probability of marijuana use by the following grade, as evidenced by the transition probability from the ACI to the ACIM stage.

The hypothesis that inhalants operate as a partial gateway to marijuana use (Hypothesis 1.2) was supported only for white females in the 6th–7th grade transition, although evidence suggested that inhalant use at 7th grade does increase the probability of transitioning to marijuana use at 8th grade for the later transition period. There was no evidence of a gateway role for inhalants for the other groups. Table 5.61 summarizes the final models selected for each group and indicates whether the models included inhalants (Research Question 1), whether inhalant use appears to precede marijuana use for a significant number of adolescents (Hypothesis 1.1), and whether there was evidence for a (partial) gateway relationship between inhalants and marijuana (Hypothesis 1.2).

Based on the LTA models identified here, Research Question 2, which examines the prospective relationship between inhalants and other gateway drugs, can be addressed only for white females. Specifically, models identified for white females allow for an investigation of the strength of association between inhalant use at one grade and the probability of transitioning to marijuana use at the following grade.

Table 5.61 Final Selected Models for Each Sample

	6th–7th Grade					7th–8th Grade				
	No. of stages	Stages	Inhalants Present?	Inhalants Precede Marijuana?	Inhalant Gateway?	No. of stages	Stages	Inhalants Present?	Inhalants Precede Marijuana?	Inhalant Gateway?
White males	4	N, A, AC, ACIM	Yes	No	No	5	N, A, AC, ACM, ACIM	Yes	No	No
White females	6	N, A, C, AC, ACI, ACIM	Yes	Yes	Yes	6	N, A, C, AC, ACI, ACIM	Yes	Yes	No[a]
African American males	3	N, AC, ACM	No	No	No	6	N, A, AC, CM, ACM, ACIM	Yes	No	No
African American females	4	N, A, C, AC	No	No	No	4	N, A, AC, ACM	No	No	No

[a] Although evidence for a partial gateway relationship was not present, the use of inhalants at baseline (7th grade) was associated with a significant probability of transitioning to marijuana use at 8th grade for white females.

5.2 Research Question 2: Does the Probability of Transitioning from Inhalant Use to Other Drug Use Remain after Controlling for Demographic Factors and Key Psychosocial Predictors of Adolescent Drug Use?

For white females, there appears to be a strong association between inhalant use and transitioning to later marijuana use; for the 464 white females in the 6th–7th grade sample, there is evidence to support a partial gateway relationship, whereas for the 954 in the 7th–8th grade sample, there is evidence to support a relationship, but not a gateway relationship, between inhalants and marijuana. To determine whether these associations persist after controlling for factors that may represent common liabilities for drug use transitions, LTA with covariates was conducted.

A total of 13 variables were entered one at a time to determine the independent effects of each factor on the transition probability from inhalant use to marijuana use. Variables that were found to be associated with a decrease in the probability of transitioning from inhalant use to marijuana use were entered into multivariate models. Frequencies and response codes for each of the covariates are listed in Appendix A. Scales were recoded into dichotomous variables to ease interpretation of results, to facilitate estimation with small sample sizes, and because most of the variables were highly skewed. Age remains continuous, and the sensation-seeking variable was reverted to the original scale for the 6th–7th grade sample due to problems with model convergence using the dichotomous measure.

The variables are coded so that high scores indicate high risk. "Protective factors" such as religiosity are reverse coded so that high scores indicate low scores on the variable.

Covariates are included in LTA models via a logistic link function, resulting in logistic regression coefficients. Covariates can be included as predictors of both the initial status (δ) and the transition probabilities (τ), resulting in two additional sets of parameters (β

—beta parameters) estimated by the LTA. In this case, the δ and τ parameters are calculated as functions of β parameters and covariates. The interpretation of a transition probability when covariates are included becomes the probability of transitioning to status B at time t + 1, given membership in status A at time t *and* the effect of the covariates.

Given that the transition probability estimate for an LTA with covariates model is a function of both Time 1 status and the covariates, it is possible to determine if, after adding covariates, the relationship between inhalants and marijuana remains; such a finding would be consistent with gateway theory. If, on the other hand, the transition probability diminishes to zero, this would suggest that responses to the covariates fully account for the relationship. This facilitates the analysis for Research Question 2: by including covariates, it is possible to determine whether the probability of transitioning to marijuana use, given previous inhalant use, remains after controlling for the covariates. The primary parameter of interest is the transition probability (τ) estimate for the ACI to ACIM transition. The extent to which inhalant use serves as a gateway to marijuana use will be determined by assessing whether the transition probability decreases substantially as a result of adding covariates.

While analyses without covariates allow for missing data and include all cases via maximum likelihood estimation, missing values on the covariates are not allowed, and cases with missing values on the covariates are deleted listwise. The amount of missing data for the covariates is modest but not trivial; for the 6th–7th grade sample, the frequency of missing data for the covariates ranged from 0 to 4.1%, and 10.1% of this sample were missing data on at least one covariate. For the 7th–8th grade sample, the frequency of missing data for the covariates ranged from 0 to 9.6%, and 15.5% of the sample were missing data for at least one of the covariates. Additionally, DA or other methods for producing standard errors,

establishing statistical significance, and conducting hypothesis testing are not currently available. Therefore, these results should be interpreted as preliminary and suggestive rather than definitive.

For consistency, the covariates were included to predict both (a) baseline (time 1) latent stage membership (the δ parameters) and (b) the probability of transitioning from the ACI stage to the ACIM stage (the τ parameters); other transition probabilities were not the focus of this study and were therefore not estimated. Because the focus for this research question is the transition from inhalant use (ACI) to marijuana use (ACIM), the results described in detail specifically relate to that portion of the analysis. However, odds ratios for the effect of each predictor on baseline stage membership are presented in Appendices B (for the 6th–7th grade transition) and C (for the 7th–8th grade transition). The "no use" stage was specified as the reference group, so odds ratios larger than 1.0 indicate an increased risk of membership in a latent stage relative to the non-users. The presented odds ratios are for covariates entered separately (unconditional estimates).

In general, the results suggest that scores on the covariates representing greater levels of risk are associated with increased odds of being in one of the drug use stages, and the findings are especially strong for the more advanced drug use stages (AC, ACI, and ACIM). The results are fairly uniform; the size of the odds ratios increases as the stages advance. The odds ratios are generally largest for individuals in the ACIM stage, and are larger for the ACI stage than for the AC stage for most covariates.

SAS Proc LTA provides an omnibus test for the overall significance of the covariates on latent status membership at baseline (the δ parameters). For each covariate, the specified model, where baseline stage membership is predicted by the covariate, is compared to the

model where that covariate has been removed. The p-value is obtained by comparing twice the difference in log-likelihood values for the two models to a chi-square distribution (Lanza et al., 2008). A significant p-value for a covariate suggests that a model that includes the covariate as a predictor of baseline latent stage membership provides a superior overall fit than a model without the covariate. It is important to note that these p-values do not relate to the effect of the covariates on the transition probabilities; p-values for that component of the model are not currently available for SAS Proc LTA. These results are included here to give a general indication of whether the covariates are significantly associated with baseline stage membership, thus improving model fit.

Results from omnibus significance tests for each of the individual covariates are presented in Table 5.62. For the 6th–7th grade sample, grade point average (GPA) and academic aspirations were not significantly associated with baseline latent stage membership. For the 7th–8th grade sample, all of the variables were significant ($p < .05$).

Table 5.62 Omnibus Significance Tests for Baseline Covariates

Covariate	p-value	
	6th–7th Grade	7th–8th Grade
Age	p < .0238 (*N* = 464)	p < .0423 (*N* = 954)
Social values	p < .0001 (*N* = 461)	p < .0001 (*N* = 872)
Grade point average	p < .9147 (*N* = 449)	p < .0009 (*N* = 875)
School attachment	p < .0010 (*N* = 457)	p < .0001 (*N* = 883)
Mother's disapproval of drug use	p < .0001 (*N* = 452)	p < .0001 (*N* = 863)
Religiosity	p < .0024 (*N* = 454)	p < .0024 (*N* = 874)
Perceived drug use at school	p < .0001 (*N* = 450)	p < .0001 (*N* = 875)
Any drug use, five closest friends	p < .0001 (*N* = 461)	p < .0001 (*N* = 888)
Tolerant of any drug use, five closest friends	p < .0001 (*N* = 460)	p < .0001 (*N* = 883)
Perceived availability of drugs	p < .0001 (*N* = 447)	p < .0001 (*N* = 874)
Academic aspirations	p < .0721 (*N* = 458)	p < .0001 (*N* = 871)
Problem behavior	p < .0004 (*N* = 460)	p < .0001 (*N* = 880)
Sensation seeking	p < .0001 (*N* = 445)	p < .0001 (*N* = 862)

Note: Omnibus significance based on beta parameter test (Type III) for baseline covariates, based on change in 2*(log-likelihood).

5.2.1 Effects of the Individual Covariates on the Transition from the ACI Stage to the ACIM Stage (Bivariate Analyses)

To assess the degree to which each covariate independently influences the transition from the ACI stage to the ACIM stage, separate LTA-with-covariates models were run, each with only one of the covariates included (bivariate analysis). Table 5.63 presents odds ratios for the 6th–7th grade and the 7th–8th grade transitions. For these analyses, the odds ratios reflect the odds of transitioning from the ACI to the ACIM stage relative to remaining in the same stage at both time points. All of the covariates except for age and sensation-seeking (at 6th grade) are dichotomous, and all are scaled so that the high score indicates greater general "risk." Examining these odds ratios would allow us to address the following question: *Do respondents with scores indicating greater risk on the covariate have greater odds of transitioning from the ACI stage to the ACIM stage than those with lower risk scores?*

This question is not the focus of the current study, because the research question of interest deals with whether the probability of transitioning from the ACI to the ACIM stage remains after *controlling* for the effects of the covariates. No a priori hypotheses were made regarding the expected effects of these covariates on the transition, aside from the hypothesis that the probability of transitioning will remain after controlling for the effects of the covariates.

These results are presented to provide an example of the results that are produced via this analytic approach but are not interpreted in detail. For the 6th–7th grade transition period, low social values (OR = 1.60), low school attachment (OR = 1.52), a mother without a perceived strong disapproval of any drug use (OR = 10.83), having close friends who use drugs (OR = 2.03), high perceived availability of drugs (OR = 5.22), and high sensation-seeking (OR = 1.20) were associated with increased odds of transitioning from the ACI stage

to the ACIM stage. For example, respondents who reported having one or more close friends who use drugs had odds of transitioning from the ACI to the ACIM stage that were two times greater than the odds for someone with no close friends who use drugs. Similarly, respondents with higher than average perceived availability of drugs had more than five times greater odds of transitioning from ACI to ACIM than did those with lower than average perceived availability.

These results should be interpreted with great caution; although the original sample size for the two samples were relatively large (464 and 954 for the 6th–7th and 7th–8th grade samples, respectively), these analyses are focused only on those who were in the ACI stage at baseline, a substantially smaller sample size. For the 6th–7th grade sample, based on the results reported in Section 5.1, approximately 19 females (~4%) are estimated to be in the ACI stage at baseline. Of these, roughly 6 (~31%) are expected to transition to the ACIM stage. For the 7th–8th grade sample, 67 (~7%) females are estimated to be in the ACI stage at baseline, with 11 expected to transition to the ACIM stage.

Table 5.63 Odds Ratios Reflecting the Effects of the Covariates on Transitioning from Inhalant Use (ACI) to Marijuana Use (ACIM) for White Females in the 6th–7th and 7th–8th Grade Samples

Covariate	Odds Ratios	
	6th–7th Grade	7th–8th Grade
Age	1.01	1.00
(low) Social values	1.60	1.11
(low) Grade point average	0.67 (1.49)	1.80
(low) School attachment	1.52	2.76
(low) Mother's disapproval of drug use	10.83	0.42 (2.38)
(low) Religiosity	0.56 (1.79)	4.83
(high) Perceived drug use at school	0.34 (2.94)	0.22 (4.55)
(yes) Any drug use, five closest friends	2.03	1.22
(yes) Tolerant of any drug use, five closest friends	0.50 (2.00)	0.13 (7.63)
(high) Perceived availability of drugs	5.22	6.75
(low) Academic aspirations	0.25 (5.00)	2.46
(high) Problem behavior	0.59 (1.69)	2.23
(high) Sensation seeking[a]	1.20	9.82

[a] Sensation seeking is a continuous variable in the 6th–7th grade analyses; it is binary in the 7th–8th grade analyses.

Note: Inverse odds ratios are displayed in parentheses.

For the 7th–8th grade transition period, all but four of the covariates are associated with increased odds of transitioning from ACI to ACIM. As with the 6th–7th grade transition, high perceived drug use at school and having any friends who are perceived to be tolerant of drug use are associated with lower odds of transitioning.

Again, the primary purpose of these analyses is to determine whether the probability of transitioning from inhalant use (ACI) to marijuana use (ACIM) remains after controlling for each of the covariates. In an LTA without covariates, the transition probability τ is interpreted as the probability of transitioning to a stage at time $t + 1$, given membership in a previous stage at time t. With covariates added to the model, the transition probability reflects the probability of transitioning to a stage at time $t + 1$, given membership in a previous stage at time t *and* controlling for the effect of the covariate. A covariate may

increase (or decrease) the odds of transitioning from the ACI stage to the ACIM stage, as illustrated in Appendices B and C; how the covariate affects the transition probability is a related but different matter and is the primary focus of this LTA-with-covariates.

Table 5.64 presents the transition probabilities for the ACI to ACIM transition, for both transition periods, after controlling for each of the covariates separately. The original transition probabilities for the 6th–7th and 7th–8th grade transitions were 0.29 and 0.19, respectively. For both transition periods, several covariates are associated with decreases in the transition probability, suggesting that the covariates partially explain the probability of transitioning from the ACI stage to the ACIM stage. The largest effect for the 6th–7th grade transition is for the covariate measuring whether the adolescent perceives that his or her mother strongly disapproves of any drug use; inclusion of this covariate causes the transition probability to drop from 0.29 to 0.11, a 62% decrease. Sensation seeking has the largest effect on the transition probability for the 7th–8th grade period (reducing the probability from 0.19 to 0.13, a 32% decrease).

Table 5.64 Probabilities of Transitioning to Marijuana Use (ACIM) at Time 2, Given Inhalant Use (ACI) at Time 1 AND Controlling for Covariates at Time 1 (Bivariate Analysis)

Covariates	Transition Probabilities	
	6th–7th Grade	7th–8th Grade
No Covariate (Baseline Model)	*0.29*	*0.19*
Age	0.29	0.19
(low) Social values	0.19	0.20
(low) Grade point average	0.26	0.15
(low) School attachment	0.29	0.16
(low) Mother's disapproval of drug use	0.11	0.17
(low) Religiosity	0.22	0.15
(high) Perceived drug use at school	0.34	0.23
(yes) Any drug use, five closest friends	0.28	0.17
(yes) Tolerant of any drug use, five closest friends	0.38	0.29
(high) Perceived availability of drugs	0.18	0.15
(low) Academic aspirations	0.27	0.15
(high) Problem behavior	0.31	0.14
(high) Sensation seeking	0.26	0.13

5.2.2 Multivariate Effects of the Covariates on the Transition from the ACI Stage to the ACIM Stage

As a final test of whether the transition from ACI to ACIM remains after controlling for covariates, a series of multivariate models were estimated. The covariates were rank-ordered based on the extent to which they decreased the transition probability in the bivariate analyses reported above. The variables were then entered sequentially, starting with the top-ranked variable and then adding the next ranked variable. Results of these multivariate analyses are provided separately for the 6th–7th (Table 5.65) and the 7th–8th (Table 5.66) grade transition periods. The results indicate that for the 6th–7th grade transition, a model containing both the mother's disapproval of drug use measure and the perceived availability of drugs measure had the strongest impact on the size of the transition probability—dropping it to 0.09.

Table 5.65 Probabilities of Transitioning to Marijuana Use (ACIM) in 7th Grade, Given Inhalant Use (ACI) and Covariates in 6th Grade (Multivariate Analysis)

Model	Conditional Transition Probability (ACI to ACIM)	Odds Ratios Reflecting the Effects of Covariates on Transition from ACI to ACIM	Significance (p-value)
Unconditional (No Covariates) (*N* = 464)	0.29		
Model 1 (*N* = 452)	0.11		
Mother's disapproval of drug use		10.83	p < .0001
Model 2 (*N* = 437)	0.09		
Mother's disapproval of drug use		9.26	p < .0001
Perceived availability of drugs		5.00	p < .0001
Model 3 (*N* = 435)	0.12		
Mother's disapproval of drug use		3.97	p < .0001
Perceived availability of drugs		2.84	p < .0001
Social values		1.24	p < .0001
Model 4 (*N* = 429)	0.14		
Mother's disapproval of drug use		2.61	p < .0001
Perceived availability of drugs		1.81	p < .0001
Social values		1.43	p < .0001
Religiosity		1.09	p < .0774
Model 5 (*N* = 421)	0.19		
Mother's disapproval of drug use		1.30	p < .0304
Perceived availability of drugs		1.05	p < .0037
Social values		1.11	p < .0052
Sensation seeking		1.05	p < .0001
Model 6 (*N* = 421)	0.20		
Mother's disapproval of drug use		1.23	p < .2338
Perceived availability of drugs		1.04	p < .1615
Social values		1.05	p < .0128

(continued)

Table 5.65 Probabilities of Transitioning to Marijuana Use (ACIM) in 7th Grade, Given Inhalant Use (ACI) and Covariates in 6th Grade (Multivariate Analysis) (continued)

Model	Conditional Transition Probability (ACI to ACIM)	Odds Ratios Reflecting the Effects of Covariates on Transition from ACI to ACIM	Significance (p-value)
Sensation seeking		1.04	$p < .0130$
Any drug use, five closest friends		1.02	$p < .0029$
Model 7 ($N = 417$)	0.20		
Mother's disapproval of drug use		1.20	$p < .2398$
Perceived availability of drugs		1.02	$p < .2677$
Social values		1.05	$p < .0291$
Sensation seeking		1.02	$p < .0641$
Any drug use, five closest friends		1.03	$p < .0136$
Religiosity		1.01	$p < .9914$

For the 7th–8th grade transition, none of the multivariate models resulted in a greater decrease in the transition probability than evidenced for a model including only sensation seeking as a covariate. The overall decrease associated with covariates is less in the 7th–8th grade transition (compared to the 6th–7th grade transition), although the initial transition probability is lower for the 7th–8th grade transition to begin with. After controlling for covariates that were found to be associated with a decrease in the transition probability, the "adjusted" probability of transitioning from ACI to ACIM was 0.09 at 6th–7th grade and 0.13 at 7th–8th grade.

Table 5.66 Probabilities of Transitioning to Marijuana Use (ACIM) in 8th Grade, Given Inhalant Use (ACI) and Covariates in 7th Grade (Multivariate Analysis)

Model	Conditional Transition Probability (ACI to ACIM)	Odds Ratios Reflecting the Effects of Covariates on Transition from ACI to ACIM	Significance (p-value)
Unconditional (No Covariates) ($N = 954$)	0.19		
Model 1 ($N = 862$)	0.13		
Sensation seeking		9.82	p < .0001
Model 2 ($N = 852$)	0.14		
Sensation seeking		5.16	p < .0001
Problem behavior		1.19	p < .0001
Model 3 ($N = 836$)	0.15		
Sensation seeking		2.60	p < .0001
Problem behavior		0.84	p < .0008
Perceived availability of drugs		2.70	p < .0001
Model 4 ($N = 822$)	0.17		
Sensation seeking		1.86	p < .0001
Problem behavior		1.07	p < .0008
Perceived availability of drugs		1.81	p < .0001
Academic aspirations		1.30	p < .1549
Model 5 ($N = 826$)	0.16		
Sensation seeking		1.71	p < .0001
Problem behavior		0.67	p < .0006
Perceived availability of drugs		2.34	p < .0001
Religiosity		2.11	p < .0025
Model 6 ($N = 818$)	0.18		
Sensation seeking		1.43	p < .0001
Problem behavior		0.79	p < .0015
Perceived availability of drugs		1.70	p < .0001
Religiosity		1.59	p < .0029
GPA		0.98	p < .0282

(continued)

Table 5.66 Probabilities of Transitioning to Marijuana Use (ACIM) in 8th Grade, Given Inhalant Use (ACI) and Covariates in 7th Grade (Multivariate Analysis) (continued)

Model	Conditional Transition Probability (ACI to ACIM)	Odds Ratios Reflecting the Effects of Covariates on Transition from ACI to ACIM	Significance (p-value)
Model 7 ($N = 816$)	0.18		
Sensation seeking		1.22	$p < .0001$
Problem behavior		0.92	$p < .0047$
Perceived availability of drugs		1.37	$p < .0001$
Religiosity		1.32	$p < .0102$
GPA		0.99	$p < .0713$
School attachment		1.21	$p < .1452$
Model 8 ($N = 806$)	0.16		
Sensation seeking		1.30	$p < .0001$
Problem behavior		1.00	$p < .0138$
Perceived availability of drugs		1.37	$p < .0001$
Religiosity		1.25	$p < .0639$
GPA		1.19	$p < .1138$
Mother's disapproval of drug use		0.83	$p < .0001$
Model 9 ($N = 812$)	0.16		
Sensation seeking		1.36	$p < .0001$
Problem behavior		1.07	$p < .0167$
Perceived availability of drugs		1.45	$p < .0001$
Religiosity		1.25	$p < .0762$
Mother's disapproval of drug use		0.84	$p < .0032$
Any drug use, five closest friends		0.97	$p < .0001$

These analyses sought to address Research Question 2 (*Does the probability of transitioning from inhalant use to other drug use remain after controlling for demographic factors and key psychosocial predictors of adolescent drug use?*) by examining the effects of covariates on the probability of transitioning from the ACI to the ACIM stage. The stated hypothesis for this study (Hypothesis 2.1), based on the gateway hypothesis, is as follows: *The probability of transitioning from inhalant use will remain after controlling for baseline drug use, demographic factors, and common liability variables.* For both transition periods, the transition probability remained positive after controlling for covariates; a finding that the transition probability remains after controlling for covariates provides some evidence in support of a gateway relationship between inhalants and marijuana by suggesting that there is an independent effect of inhalant use on transitioning to marijuana use.

However, although the transition probability remains after controlling for covariates, the size of the probability does diminish substantially, by 62% for the 6th–7th grade transition and by 32% for the 7th–8th grade transition. This provides at least some support for the competing common-liability view of drug use, that underlying characteristics, particularly characteristics that increase opportunities to use drugs, explain the relationship between drugs.

It is possible that additional unmeasured covariates would further decrease the effect of inhalants, and without statistical significance testing, it is not currently possible to determine if the reduction in the probability is significant. But based on these preliminary results, it appears that there is a direct effect of using inhalants on transitioning to marijuana use among white female adolescents in this sample.

CHAPTER 6

DISCUSSION

This study used latent transition analysis (LTA) to explore the relationship between adolescent inhalant use and the use of the three drugs most commonly referred to as "gateway drugs": alcohol, cigarettes, and marijuana. Although a few studies (e.g., Dinwiddie, Reich, & Cloninger, 1991a; Schutz, Chilcoat, & Anthony, 1994; Johnson, Schutz, Anthony, & Ensminger, 1995) have documented a prospective relationship between inhalant use and later hard drug use (particularly heroin use), to date no studies have used longitudinal data and stage-based analytic techniques to examine whether the drug use sequence for gateway drugs can be extended to include inhalants; doing so was the primary purpose of the current study. This chapter discusses the major study findings, study strengths and limitations, and implications and areas of future research.

6.1 Summary of Findings

6.1.1 Summary of Findings for Research Question 1: Can the Gateway Hypothesis be Extended to Include Inhalants for African American and White, Male and Female Adolescents in Grades 6 through 8?

The traditional, widely reported, and empirically tested gateway hypothesis posits that drug use occurs in a sequential manner, beginning with the use of legal, widely available drugs and progressing to the use of "hard" drugs. Analyses to date have focused on alcohol, cigarettes, and marijuana as the primary gateway drugs. Among adolescent populations, these substances are relatively easy to obtain and national prevalence estimates (primarily for

secondary school students) consistently indicate that these are the most widely used substances.

A review of data for younger adolescents (in grades prior to and including 8th grade) suggests that inhalants may be as commonly used as marijuana for some segments of the young adolescent population (Johnston, O'Malley, Bachman, & Schulenberg, 2005; Wu, Pilowsky, & Schlenger, 2004; Johnston, O'Malley, & Bachman, 2001). Inhalants are widely available and may serve as entrée to experiences with drugs and with drug-using peers. Inhalants share these characteristics with the other gateway drugs. If, as the gateway hypothesis posits, drug use typically begins with the use of the most widely available and widely used drugs, then inhalants may operate as an important unidentified gateway drug.

For these reasons—the relatively high prevalence of inhalant use among young adolescents and the wide availability of inhalants in general—it was hypothesized that inhalant use would precede marijuana use for a significant number of adolescents in this sample (Hypothesis 1.1) and more formally that inhalant use would operate as a partial gateway to marijuana use (Hypothesis 1.2).

Moreover, previous research has suggested that there may be important differences in general drug use sequencing by gender and race (Kandel & Yamaguchi, 2002; Yamaguchi & Kandel, 2002). As this study is the first to evaluate where inhalants fit within the gateway drug use sequence, it was deemed necessary to determine whether the drug use sequence that includes inhalants differs by race and gender. Therefore, the analyses were carried out separately for four groups (white males, white females, African American males, and African American females) and at two transition periods (6th–7th grade and 7th–8th grade). It was hypothesized that the gateway drug use sequence would differ for the groups, with inhalants

serving a more prominent role in the drug use sequence for whites and for females (Hypothesis 1.3).

Three key findings emerged from this analysis of Research Question 1: (1) there are clear differences in gateway drug use sequencing between the four groups, (2) a model of gateway drug use sequencing that includes inhalants can be identified for white males and white females at both the 6th to 7th and the 7th to 8th grade transition periods and for African American males in the 7th to 8th grade transition, but (3) evidence that inhalant use may operate as a partial gateway to marijuana use was only observed for white females during the 6th to 7th grade transition.

6.1.1.1 Differences in Gateway Drug Use Sequencing

Separate models of gateway drug use transitions were identified for each gender/race group, indicating that important variations in drug use sequencing exist between the groups. For the 6th to 7th grade transition, models were identified for each group that appeared to fit the data relatively well based on the G^2 value being lower than the model degrees of freedom—a rough rule-of-thumb indicating good overall model fit. For the 7th–8th grade transition, only the model identified for white females appeared to have a good fit to the data; when considering responses patterns for four drug use measures (alcohol, cigarettes, inhalants, and marijuana), the analyses failed to identify a well-fitting model for white males and African American males and females.

Approximately 49% of white males in the 6th grade sample were in the "No Use" latent stage, a number that was significantly less than for the other groups. This finding is consistent with published national prevalence estimates that suggest in general that white male adolescents have among the highest drug use prevalence rates. This finding suggests

that 6th grade may be late in white male adolescent development to assess gateway drug use initiation—a high prevalence of these adolescents have already initiated drug use by this time.

Conversely, the 6th–7th grade transition period appears to be an especially important time for white female drug use development. Sixty-one percent of white females were estimated to still be in the "no use" latent stage at 6th grade, and the overall advance rate for white females (0.36) was substantially larger than for the other groups. The advance rate is an overall measure of the probability of progressing to a more advanced latent stage, and for white females this number suggests that 36% of the respondents transitioned to a more advanced stage between the 6th and 7th grades, compared to 27%, 26%, and 30% of white males, African American males, and African American females, respectively.

Although previous studies have not considered inhalants within a gateway drug use sequence, the finding that drug use patterns differ by race and/or gender has been reported. For instance, previous research has indicated that cigarette use is a stronger predictor of transitioning to marijuana for females than for males (Kandel & Yamaguchi, 2002). Similarly, there is some evidence from previous research that alcohol and cigarettes are weaker predictors of marijuana use among African American adolescents and that ethnic minority groups are less likely to follow the traditionally espoused gateway sequence (Yamaguchi & Kandel, 2002).

In the United States, male and female adolescents have similar prevalence rates for inhalant use, whereas females typically have lower rates of use for other drugs; inhalant use appears to be on the rise among adolescent females, while remaining stable for males (Substance Abuse and Mental Health Services Administration [SAMHSA], 2007). This

suggests that inhalants may serve an especially important role for female adolescents, a supposition supported here by the finding that inhalants are an important part of drug use sequencing for white females. The finding that inhalants were not an important part of the gateway sequence for African Americans likely in part reflects the fact that African American adolescents have substantially lower rates of inhalant use than whites (CDC, 2006).

An initial indication of these gender/race differences was evidenced in the observed response patterns for the four groups. For the current study, four dichotomous items were assessed at two time points, resulting in a possible total of 256 (2^{4*2}) unique response patterns; a high number of unique response patterns is indicative of heterogeneity of responses for a group, whereas a low number increases the likelihood that a parsimonious model describing the drug use sequence can be identified. White females had low numbers of unique observed response patterns relative to the other groups, suggesting greater homogeneity in drug use sequencing. In contrast African American females, and most clearly African American males, exhibited a great deal of heterogeneity in their drug use response patterns over time.

The general effect of this increased heterogeneity was to increase the instability of the estimates for the models; stringent efforts made in this study to identify the best fitting and most stable models for each group may therefore have resulted in models that were conservative. It was certainly more difficult to identify stable models for African American adolescents in these analyses, and, despite frequency estimates indicating that inhalants were in fact used (albeit to a lesser degree than for white adolescents), the selected models failed

to include inhalants in any of the stages (except for African American males transitioning from 7th to 8th grade).

It should be noted that the models selected and analyzed for this study are essentially models that best fit the data after adjusting for measurement error. Measurement error likely had a significant impact on model selection and study findings. As a latent variable approach, LTA adjusts for measurement error, an important advantage of this approach. When not adjusted for, measurement error for categorical data results in misclassification of individuals, with a tendency in transition models to make it appear that there has been more change over time than has really occurred (Collins, 2002). LTA adjusts for measurement error, potentially giving a more realistic, and certainly a more conservative, estimate of the amount of change.

In this study, there is a great deal of measurement error associated with the transition matrix. Descriptive analyses suggest that a high percentage of respondents who report ever use of a substance at baseline report never use for the same drug at the next time point. This type of response inconsistency, known as "recanting," is very common in longitudinal studies (Fendrich, 2005). Because the models estimated were "onset" models, the transition matrix was constrained to allow for only two possibilities: remaining in the same stage or transitioning to a more advanced stage over time. Responses that fail to conform to these restrictions (for instance, reporting alcohol use at baseline but "no use" at the next time point) are treated as measurement error in LTA.

Recanting rates differ across substances and between the four race/gender groups. Recanting is far more prevalent for inhalants than for the other three substances for all of the groups—rates of recanting on the inhalant use item range from 28.5% for white females

transitioning from 7th to 8th grade to 51.8% for African American females for the same transition period. This finding is in line with several studies that have found a consistent and positive association between recanting prevalence and the perceived social stigma of a drug (Pedersen, 1990; Fendrich & Mackesy-Amiti, 2000; Percy, McAlister, Higgins, et al., 2005; Fendrich & Vaughn, 1994; Fendrich & Kim, 2001; Stueve & O'Donnell, 2000) and specifically that respondents were more likely to recant inhalants than marijuana, alcohol, or tobacco (Fendrich & Mackesy-Amiti, 2000; Percy, McAlister, Higgins, et al., 2005; Stueve & O'Donnell, 2000).

African American males and females in this sample more frequently recanted on all of the substances, with the notable exception that African American males at both time points recanted less frequently than the other adolescent groups on the marijuana use item. Again, this finding is consistent with a number of previous studies that have consistently demonstrated that African American respondents are more likely than white respondents to retract drug use responses (Fendrich & Mackesy-Amiti, 2000; Fendrich & Vaughn, 1994; Fendrich & Kim, 2001; Fendrich & Rosenbaum, 2003; Siddiqui, Mott, Anderson, & Flay, 1999; Mensch & Kandel, 1988).

The fact that LTA accounts for measurement error is a significant advantage of the approach overall—it provides a more principled way of handling measurement error that is "vastly preferable to the often used ad hoc alternative of attempting to identify data that are subject to error and discarding or revising them" (Lanza, et al., 2005, p. 85). However, the overall fit for these models of drug use sequencing is decreased in the presence of measurement error (Lanza & Collins, 2002), and the measurement parameters (ρ) are weakened (Tang, Lanza, & Collins, 2001). Given the higher rates of recanting for the African

American sample, it is likely that the models selected are overly conservative and that the absence of an inhalant-use stage reflects in part the impact recanting had on the measurement parameters.

Together, these findings highlight the importance of considering group differences for these analyses. An alternative approach facilitated by LTA would have been to identify a single model for the full sample, and then include a latent grouping variable representing the four race/gender groups. This approach would allow for a direct comparison of the latent stage membership and the transition probabilities, but would assume that the same drug use sequence was appropriate for each group. Results from this study indicate that there are important differences between the four groups, a finding that could only be elucidated by conducting the analyses separately.

6.1.1.2 Inhalant Use in the Gateway Drug Use Sequence

For white males at both transition periods and African American males in the 7th–8th grade transition, models were identified that included inhalants—indicating that the gateway model may be extended to include inhalants for these groups. This finding is consistent with Hypothesis 1.1, although the overall fit for these models was poor, except for white males in the 6th–7th grade sample. As noted above, the poor model fit may in part reflect the large amount of measurement error present, particularly for African American males.

For both groups, inhalant use was present as part of a latent stage including the use of all four of the gateway drugs (ACIM). In other words, based on these analyses, it appears that inhalants are primarily used by adolescents who have also used alcohol, cigarettes, and marijuana, and there is no evidence that inhalants operate as a gateway to marijuana (Hypothesis 1.2). In the 6th grade, an estimated 9% of white males were in the ACIM stage.

By the 8th grade, the prevalence was estimated at 19%; 13% of African Americans in 8th grade were estimated to be in the ACIM stage.

During the 7th–8th grade transition, the best-fitting models for both white and African American males included a separate latent stage representing the ever-use of alcohol, cigarettes, and marijuana, but not inhalants (ACM). The model for African American males also included a separate "cigarettes and marijuana" (CM) stage. For white males who have used marijuana, more have also used inhalants than not. Conversely, a majority of African American males in this sample who have used marijuana have not also used inhalants. For both groups, transitioning from one of the marijuana use stages to the inhalant use stage (ACIM) was very rare; 3% of white males in the ACM stage at 7th grade transitioned to the ACIM stage at 8th grade and 2% of African American males made the same transition. This finding conforms to the commonly cited finding that inhalant use peaks during early adolescence; it also suggests that marijuana use does not increase the probability of inhalant use.

Although not directly testable via these models, it appears that inhalant use may be related to marijuana use among white males but less so for African American males. It is possible, particularly in the case of white males, that samples from earlier ages are necessary to better identify the gateway sequence between inhalants and marijuana. But given that marijuana use does not appear to substantially increase the probability of transitioning to inhalant use, along with the relatively high proportion of marijuana users who have also used inhalants, it is conceivable that inhalant use may increase the probability of marijuana use for white males.

Results for white females in this study were unique in that at both time points a latent stage including alcohol, cigarettes, and inhalants (ACI) was present along with the ACIM stage, evidence in support of Hypothesis 1.1. In the 6th grade, prevalence in the ACI stage (4%) was slightly greater than prevalence in the ACIM stage (3%). By 8th grade, an estimated 9% of white female adolescents were in the ACI stage, a notable increase. However, the estimate for the ACIM stage in 8th grade rose sharply, to 18%, by 8th grade, suggesting that the 6th–8th grade time span is an important time of risk for marijuana initiation. It should be noted that because these models are adjusted for measurement error, the estimates can be viewed as conservative and are likely robust.

The LTA model identified for white females is the only model that allows for a direct assessment of the gateway relationship between inhalants and other drugs (specifically marijuana), which is a primary aim of this study (Hypothesis 1.2). Therefore, a discussion of the results for white females is the focus for the remainder of this section.

6.1.1.3 Inhalant Use as a (Partial) Gateway to Marijuana Use for White Females

Using a recently proposed operational definition of the gateway hypothesis (Maldonado-Molina, 2005), this study is the first to formally identify a potential "partial" gateway relationship between inhalant use and marijuana use for white adolescent females. For the 6th to 7th grade transition, the use of inhalants (in conjunction with having ever used alcohol or cigarettes) during the 6th grade was associated with a 0.31 probability of transitioning to marijuana use by the 7th grade. The probability of transitioning from inhalants to marijuana was greater than the reverse possibility (marijuana to inhalants), which did not exist in this model. The probability of transitioning to marijuana use at 7th grade given inhalant use in 6th grade was also greater than the probability of transitioning to

marijuana having never used inhalants (for a "complete" gateway relationship to exist, all individuals who transition to marijuana use would have needed to have first used inhalants).

In sum, these results suggest a partial gateway relationship, where inhalant use operates as a partial gateway to marijuana for some white female adolescents during the 6th to 7th grade transition. Criteria for a partial gateway relationship were not met for the 7th to 8th grade transition; however, the probability of transitioning to marijuana use by 8th grade given inhalant use in 7th grade was large (0.17), suggesting that inhalant use increases the probability of transitioning to marijuana use in this later period as well.

Coupled with recent findings that inhalant use is increasing for white females while remaining stable for the U.S. adolescent population as a whole (SAMHSA, 2007), the results of this study suggest that white female adolescents transitioning into secondary school and the teen years represent an important population-at-risk for inhalant use initiation. The use of inhalants also appears to place these female adolescents at an increased risk of initiating marijuana use.

6.1.2 Summary of Findings for Research Question 2: Is Inhalant Use Associated with Gateway Drug Use Transitions when Controlling for Demographic Factors and Key Psychosocial Predictors of Adolescent Drug Use?

The latent transition model identified for white females includes a direct pathway from the ACI stage to the ACIM stage. Evidence for this model suggests that inhalants may operate as a partial gateway to marijuana use for young white female adolescents. To more fully investigate the prospective relationship between inhalant use and marijuana use for this sample of white females, LTA-with-covariates was conducted.

Three criteria for assessing the causal influence of the use of one drug on the use of other drugs have been proposed (Kandel & Jessor, 2002). The first criterion is evidence that those who use a drug or drugs are significantly more likely to have used the supposed

gateway drug. The second criteria is evidence that the use of the gateway drug typically precedes the use of the other drugs—the probability of transitioning from the gateway drug to the other drug(s) should be significantly greater than the probability of transitioning from the use of the later drug(s) to the supposed gateway drug (Maldonado-Molina, 2005). These criteria form the basis for the partial gateway condition described earlier.

The third and final proposed criteria for assessing causal influence is evidence that the association between early gateway drug use and later other drug use remains significant after controlling for potentially confounding variables, particularly factors that might be common causes of both gateway and later drug use. Critics of the original gateway hypothesis argue that while there is evidence that drug use tends to occur in a certain order, drug use transition probabilities are the result of factors such as an underlying propensity and increased opportunities to engage in problem behavior (e.g., Jessor & Jessor, 1977; Donovan & Jessor, 1985; Jessor, 1987, 1991; Donovan et al., 1988; Costa, Jessor, & Donovan, 1989; Donovan, Jessor, & Costa, 1991).

No identified studies have yet investigated inhalants as a gateway drug, and few studies have explored whether the transition probabilities between the traditional gateway drugs remain after controlling for the influence of potentially confounding variables thought to represent common liabilities for drug use (Rebellon & Van Gundy, 2006; Tarter et al., 2006). Therefore, this study represents a first attempt at assessing the causal influence of inhalant use on marijuana use for white female adolescents by accounting for the effects of a wide range of covariates on the probability of transitioning from inhalant use (ACI) to marijuana use (ACIM).

At both transition periods, several covariates were associated with a decrease in the probability of transitioning to marijuana use, given inhalant use at the prior time. This latter finding indicates that the predictive relationship between inhalants and marijuana is at least partially confounded by other factors.

For the 6th to 7th grade transition period, controlling for an adolescent's perception of *whether their mother disapproves of all drug use* and their perception of *whether they have easy access to drugs* resulted in a large decrease in the size of the transition probability between the ACI and ACIM latent stages, from 0.29 to 0.09. Accounting for the effects of these two variables resulted in the lowest estimated transition probability; adding additional covariates did not further decrease the transition probability.

The finding that the perceived availability measure is associated with a decrease in the transition probability is particularly noteworthy given the important differences in availability between inhalants and marijuana. One of the critiques of the gateway hypothesis is that the typical sequence of drug use may simply reflect the degree to which substances are available. Alcohol and cigarettes are widely available and have consistently been shown to precede marijuana use for the majority of adolescents who try it.

According to the gateway hypothesis, alcohol and cigarette use predict later marijuana use; critics of this view argue instead that the ordering is an artifact related to when adolescents are able to access particular classes of drugs. Inhalants, like alcohol and cigarettes, are very widely available, whereas marijuana is far less ubiquitous. It is possible that the probability of transitioning from inhalant use to marijuana use may have more to do with whether marijuana is available to the adolescent—those with access to marijuana may

be more likely to transition to use while those without access to marijuana remain in drug use stages that reflect the more widely available drugs.

Controlling for perceived access to drugs, along with perceived mother's disapproval of drug use, accounts for a good portion of the relationship between inhalant use and marijuana use in this sample. However, no combination of covariates reduces the transition probability altogether, leaving open the possibility that either the relationship has not been accounted for by other covariates that were not included in this study, or that previous inhalant use (along with alcohol and cigarette use) has an independent and robust influence on the probability of transitioning to marijuana use. The fact that so many covariates that have been identified as potential measures of general liabilities for drug use were included in this study, and that no combination of covariates was identified that could fully diminish the transition probability, is strong evidence in support of the partial gateway possibility.

During the 7th to 8th grade transition period, high versus low sensation-seeking personality was associated with a decrease in the transition probability, from 0.19 to 0.13. Adding variables did not further reduce the probability, suggesting that sensation-seeking may be particularly important in terms of predicting the transition from inhalant use to marijuana use. High versus low sensation seekers had greater odds of transitioning from the ACI to the ACIM latent stage, and accounting for sensation-seeking appears to lessen the predictive effect of inhalants on transitioning to marijuana use.

It is plausible that among this population of white female adolescents, marijuana use is perceived as more risky than inhalant use. Indeed, inhalants are widely available, and although the abuse of inhalants is technically classified as illicit, the products that are inhaled can be legally purchased. Adolescent females with high sensation-seeking propensity are

clearly more likely to try marijuana use than low sensation-seekers; for this sample, it appears that sensation-seeking distinguishes between inhalant use and marijuana use.

Factors such as sensation-seeking and perceived and actual availability of drugs may differentiate white females from other demographic groups, particularly white males, and may in part explain why inhalants are potentially an important gateway drug for this group. It is possible that on average, white females have lower sensation-seeking propensity compared to males and are therefore more likely to experiment with drugs that are particularly easy (or legal) to obtain. Indeed, for this study sample males had significantly higher mean sensation seeking scores at both 6th and 7th grades. At 6th grade, males had an average sensation seeking score (on a scale ranging from 0 to 12) of 5.07 (SD = 3.68), while the average for females was 3.61 (SD = 3.37), a difference that was highly significant (p <.001). Similarly, at 7th grade the average sensation-seeking scale score for males was 5.53 (SD = 3.84) and for females was 4.20 (SD = 3.58), again a statistically significant difference (p <.001).

Zuckerman and Kuhlman (2000) reported that in a U.S. college student sample, men demonstrated higher risk-taking tendency than women, a finding that was mediated by gender difference in the personality trait of impulsive sensation seeking. An earlier study similarly found that U.S. men tend to score higher on novelty-seeking than women (Cloninger, Przybeck, & Svrakic, 1991). Again, inhalants can be easily obtained, the effects of inhalant use tend to wear off quickly (so the use of inhalants can be easily concealed), and the perceived legal and social risks associated with inhalant use are likely lower than for drugs like marijuana. Perhaps gender differences in sensation seeking and other personality characteristics in part explain the finding that inhalants play a particularly important role in gateway drug use sequencing for white female adolescents.

In attempting to explain the finding that white females have similar inhalant use prevalence rates as white males, it has been posited that adolescent males' "overall higher likelihood of involvement with drugs may relate to their more frequent exposure to situations in which these drugs are available. Inhalants may be an exception because boys and girls have the same level of access to them" (NIDA, 2005b, p. 7). For the sample analyzed for this dissertation, based on Mann-Whitney test results, there were no significant differences in perceived access between males and females at 6th or 7th grade for alcohol and cigarettes. There was also no difference by gender in perceived access to inhalants at 6th grade. Males did have statistically higher median scores for perceived access to inhalants at 7th grade ($p < .001$) and for marijuana at both 6th grade ($p < .01$) and 7th grade ($p < .001$). These findings support the argument that females and males may have similar access to inhalants, particularly in early adolescence (6th grade), whereas marijuana use is clearly perceived as more available among males than females in this sample.

The finding of gender similarity in inhalant use highlights the potential importance of availability and access as predictors of adolescent inhalant use. Adolescent males, through earlier involvement in drugs and associations with drug-using peers, likely have greater opportunities to use drugs and are therefore more likely to exhibit, as a whole, more advanced drug use sequencing than females. Van Etten and Anthony (2001) found that across age, race, region, and urban status subgroups, after controlling for opportunities to use drugs, women were as likely as men to initiate drug use; inhalants may serve as a particularly important gateway for females because of their wide availability. Again, it is noteworthy that after controlling for perceived access to drugs, inhalants still appeared to have an important effect on transitioning to marijuana use for white females.

Interesting differences in median perceived access to each of the drugs in this study were also found between white and African American adolescents; white adolescents had significantly higher median scores for perceived access to inhalants at both 6th (p <.05) and 7th (p <.002) grades, whereas African Americans had higher scores for perceived access to marijuana at both grades (p <.002 and p <.001, respectively). These findings may reflect important contextual differences in drug use availability by race, potentially supporting the findings in this study that inhalants appear to be more important in gateway drug use sequencing for white adolescents than for African American adolescents, whereas marijuana appears to be important for African Americans, particularly African American males.

Finally, although the inclusion of covariates does appear to attenuate the partial gateway relationship between inhalants and marijuana (a finding consistent with a "common-cause" critique of the gateway hypothesis), for white females, a non-zero probability of transitioning to marijuana use given previous inhalant use remains. Inhalants appear to have a unique and important place in white female adolescent drug use sequencing. The results of this study build on previous research that suggests inhalants are a particularly important class of drugs for white females by empirically demonstrating, for the first time, a partial gateway relationship between inhalant use and marijuana use.

6.2 Strengths and Limitations

6.2.1 Strengths

This study used longitudinal data from a general population sample of young white and African American adolescents to examine the role inhalants play in gateway drug use sequencing. Much of the previous work on the gateway hypothesis has been based on cross-sectional data, preventing an examination of the temporal order by which drugs are initiated

(Kandel, 2002). The use of longitudinal data allows for a direct examination of gateway relationships and patterns of drug use during a period of adolescence (6th–8th grade) when gateway drug use initiation tends to peak.

Although the gateway hypothesis has not been previously extended to include inhalants, it served as the theoretical basis for this study. The gateway hypothesis is intrinsically a stage-based model; drug use sequencing is posited to consist of discrete stages of development rather than reflecting a continuum of behavior. An appropriate analysis of research questions based on the gateway hypothesis therefore requires an analytic approach suited to the examination of discrete stages. LTA, a longitudinal extension of latent class analysis, is uniquely suited to the analysis of models that reflect changes in discrete stages of behavior over time.

Recent advances in LTA software allowed for the inclusion of covariates in the model. This study demonstrates how, by including covariates in the analysis, it is possible to test the extent to which a transition probability is related to membership in an earlier stage, versus the effects of the covariates. Specifically, this study included covariates to determine whether the probability of transitioning from inhalant use to marijuana use for white females remained after controlling for covariates that may represent "common causes" of drug use. This approach holds great promise for testing the gateway hypothesis.

The study sample included data for 6th graders. Given the focus on gateway drugs, which are often initiated during early adolescence, the availability of data for these young adolescents was beneficial. Indeed, the results of this study suggest that the 6th–7th grade transition period, when many in the sample were transitioning into middle school, may be

particularly important for investigating drug use transitions, especially for the white female sample.

Separating the sample by race and gender was crucial—clear differences in the latent transition models were identified for each of the four study groups, suggesting that general population approaches may obscure these differences. This approach allowed for the discovery that for white females, inhalants appear to be an important drug in the early gateway sequence, whereas for other adolescents, particularly African American adolescents, inhalants appear to be far less important. This finding likely would have been obscured had the analyses been conducted for the full sample rather than separately for the four groups.

6.2.2 Limitations

The decision to divide the sample into four race/gender groups resulted in sample sizes available for analyses that were significantly reduced. Coupled with the substantial variation (heterogeneity) in the response patterns, particularly for African American males and females, these reduced samples may have precluded identifying accurate models or stable estimates. At present, there is no accepted means of conducting statistical power testing for complex latent class and latent transition models (Lanza, Flaherty, & Collins, 2003).

A rough rule of thumb for ensuring sufficient sample sizes is that the ratio of sample size to number of cells in the contingency table should not fall much below .2 (Collins, 2002). These analyses involved contingency tables with 256 cells, suggesting that a sample size of at least 51 would be needed. However, the measurement of the parameters in the model has a strong effect on sample size requirements—as measurement of the rho (ρ) parameters weakens, larger sample sizes are needed (Collins, 2002). LTA is a large sample approach; it is reasonable to assume that the instability present in the current analyses may in

part reflect insufficient sample sizes, particularly during the 6th–7th grade transition, and for African American males and females. Ideally, these analyses would be replicated with substantially larger samples.

The current study used an onset approach to the examination of gateway drug use sequencing. The substance use measures used for this study examined whether adolescents have ever used or tried alcohol, cigarettes, inhalants, or marijuana. It is possible that variations in the dosage or intensity of use of each substance are related to the likelihood of transitioning from one drug use stage to another. For example, Collins (2002) has reported that heavy drinking/drunkenness represents an important transitional stage between having ever tried alcohol and trying marijuana. In the current data set, lifetime ("ever use") measures were available for each of the four substances. A measure of past 3-month drunkenness was also available, but because it reflected only recent behavior and not lifetime onset, it was not included in the model.

A potential limitation of this study relates to the decision to consider transitions between grades in school. The assumption made here was that the major movement in drug use would be between grades rather than within grades. Considering transitions between grades simplified the interpretation of the model and is consistent with other research in this area. This is an important assumption because the duration between observations influences whether transitions between the initiation of drugs can be observed. It is possible that drug use transitions occur quickly—for instance, that the initiation of alcohol and cigarette use occurs within a short time interval. It is possible in that case that the current study design would obscure the ordering on drug initiation.

For example, there were instances in this study where direct, unexpected transitions from an early stage to a later stage (i.e., from "Alcohol Only" to "Alcohol, Cigarettes, Marijuana, and Inhalants") were present. However, these transitions may simply reflect the fact that intermediate drug use stages occurred during the period between study observations. The data set used for these analyses includes data collected every 6 months; future analyses could investigate whether using more closely spaced data increases the likelihood of identifying distinct ordered stages.

Indeed, the issue of spacing likely had direct effects on my assessment of the gateway relationship between inhalants and marijuana for white females. One criterion for a gateway relationship to exist between inhalants and marijuana is that the probability of transitioning from inhalants to marijuana must be greater than the probability of transitioning from all other stages (not including inhalants) to marijuana. I therefore calculated two probabilities, the probability of transitioning from inhalants to marijuana and the probability of transitioning from any stage without inhalants to marijuana, and compared them directly.

But based on the six-stage model found for white females, there is no evidence of any stage that includes marijuana but not inhalants, and the only stage that includes marijuana also includes inhalants (the ACIM stage). Thus, based on this model, inhalant use appears to always precede marijuana use for white females in this sample (otherwise, there would be a stage, such as ACM, that precedes the ACIM stage). This would be evidence for a complete, rather than a partial, gateway relationship.

The direct transitions from stages that do not include inhalants (N, A, C, AC) to marijuana (ACIM) could therefore be interpreted as the conditional probability of passing through the ACI stage to the ACIM stage rather than as actual direct transitions, the

assumption being that we have missed the intermediate transitions due to the spacing of our measurements. Under this assumption, there would be evidence supporting a complete gateway relationship at both grade transitions, rather than the partial relationship I report for the 6th–7th grade transition (and the lack of a relationship at the 7th–8th grade transition). However, because it is not possible to directly assess, for those individuals in the ACIM stage, whether inhalants preceded marijuana, a more conservative approach was taken. Using more closely spaced observations may provide an opportunity to more clearly elucidate the transitions between stages.

The study sample was drawn from 14 schools in three counties of North Carolina. Samples drawn from schools are susceptible to clustering effects, whereby findings are confounded by similarities among students within schools, a violation of the standard data analysis assumption that observations are independently sampled (Lanza, Flaherty, & Collins, 2002). Inhalant use may be especially prone to cluster effects, because of a reported tendency for localized, temporary epidemics of inhalant use (Mackesy-Amiti & Fendrich, 2000).

The current versions of the statistical programs used for this study do not yet accommodate random effects or sampling weights to account for this clustering. Therefore, estimates of the prevalence of drug use and the probability of membership in each latent drug use stage should be interpreted with caution as they reflect the unadjusted probabilities.

The degree of similarity (clustering) is typically measured by the intracluster (or intraclass) correlation coefficient (ICC). Ignoring significant ICCs can lead to incorrect *p*-values, confidence intervals that are not wide enough, and biased estimates (Hox, 2002), with a net effect of increasing the probability of a Type I error, sometimes substantially

(Murray, Alfano, Zbikowski, Padgett, Robinson, & Lesges, 2002). A direct means of accounting for possible clustering is not currently available in LTA. However, to determine the degree to which clustering was present for these data, I estimated the ICC for white and African American respondents on measures of alcohol, cigarette, inhalant, and marijuana use (the study outcome variables) at 6th grade. Multilevel (random intercept) logistic regression using the NLMIXED procedure (SAS, 2003) was used to estimate the ICC (Bauer & Curran, 2006).

Small, medium, and large values of the ICC are generally reported as .05, .10, and .15, respectively (Hox, 2002). In these models, 1,630 respondents were nested within 13 schools. Results (not shown) suggested that less than 0.1% of the variance in inhalant use at grade 6 was due to clustering at the school-level; this estimate was not significant (ICC = 0.0007, p <.95). Similar estimates for alcohol (ICC = 0.0008, p < .88) and cigarettes (ICC = 0.0141, p < .38) were obtained. For marijuana, the ICC was estimated at 0.1113 (p <.46), indicating that 11.1% of the variance in marijuana use at grade 6 is attributable to characteristics at the school level.

No prior studies have reported ICC estimates for school-level inhalant use and few have reported on marijuana use. Ennett et al. (1997) reported clustering estimates at the school level of .012 for current marijuana use. Several studies have reported ICCs for measures of smoking and alcohol that range from –0.0002 to 0.09 (Murray & Hannan, 1990; Murray, Rooney, Hannan, et al., 1994; Murray & Short, 1996, 1997; Siddiqui, Hedecker, Flay, & Hu, 1996; Ennett, Flewelling, Lindrooth, & Norton, 1997; Murray, Clark, & Wagenaar, 2000; Murray, Alfano, Zbikowski, et al., 2002; Scheier, Griffen, Doyle, & Botvin, 2002). Specifically, Murray et al. (2002) found in a review of the literature that ICCs for

cigarette use typically range from 0.005 to 0.05, averaging around 0.01 to 0.02. The estimate for the current study is in line with these previous estimates.

These estimates provide some indication that clustering on the outcomes of interest is very minor for alcohol, cigarettes, and inhalants. The estimate of the magnitude of the ICC for marijuana suggests that a medium ICC is present, although this result was not significant. Overall, it is likely that clustering would have only minor effects for these analyses, but future enhancements to LTA software that allow for the inclusion of random effects and/or sampling weights will facilitate a more robust handling of clustered data.

All of the measures used in the study are self-report measures. While some investigators have found that in general self-reported substance use data are valid (Colon, Robles, & Sahai, 2001, 2002; Needle, McCubbin, Lorence, & Hochhauser, 1983), it is possible that the inhalant use item in particular is subject to a variety of recall errors and reporting biases, including lack of understanding of the type of drugs being used (some youth may not consider some activities, like whip cream sniffing, to be inhalant use) and lack of candor related to the possibility that inhalants are seen as an "immature" class of drugs and are less socially acceptable (Kurtzman, Otsuka, & Wahl, 2001; Johnston, O'Malley, Bachman, & Schulenberg, 2006).

It has been proposed that broad questions about "inhalant use," such as the one used for the survey analyzed in this study, may lead to substantial underreporting of actual use (Howard, Walker, Walker, Cottler, & Compton, 1999) due to the extremely broad number of substances this term entails. For instance, in a study of inhalant use in Texas, 24% of 7th graders indicated that they sometimes "sniffed" or "huffed" one or more of a large list of common inhalants. But when the same youth were later asked a general question about their

"inhalant use," about one-half indicated that they had never used inhalants (Fredlund, 1992). Similarly, qualitative data from an unpublished focus group project suggested that youth often confuse the term "inhalants" with smoking cigarettes, marijuana, or crack or snorting heroin or cocaine (Wolfe, 1995).

Evidence for the importance of question wording has also emerged from comparisons between the three most important national youth surveys: the Youth Risk Behavior Survey (YRBS), the Monitoring the Future (MTF) survey, and the National Household Survey on Drug Abuse (NHSDA). Both the YRBS and the MTF ask two questions about lifetime and past 30 day use of "inhalants." But NHSDA asks 11 separate questions to assess the use of 10 named substances as well as the use of inhalants other than the ones listed. Lifetime use is defined as answering "yes" to any of the 11 questions. This difference in question wording leads to higher overall prevalence rates in NHSDA versus MTF and YRBS. This is particularly noteworthy in that, for most other drugs, YRBS usually produces the greatest prevalence estimates, and YRBS and MTF produce estimates higher than NHSDA. It appears that respondents may not clearly recognize all of the substances that the term "inhalant" encompasses (Brener, Grunbaum, Kann, McManus, & Ross, 2004). In any event, it is likely that this reporting bias would result in either lower initial estimates of inhalant use or higher rates of recanting. In both cases, given that LTA produces estimates that are adjusted for measurement error, this would yield overly conservative estimates—any inhalant-specific findings likely represent especially strong effects.

The LTA-with-covariates has a couple of unique limitations. The current software (SAS PROC LTA) does not produce standard errors or statistical tests for the parameter estimates, precluding any statistical hypothesis testing. Future iterations of the software will

likely include Bayesian estimation (i.e., data augmentation) to accommodate a variety of hypothesis tests (Lanza & Collins, 2008). Also, models that include covariates delete cases with any missing values. Although missingness on the covariates was modest for this study, this "listwise" deletion may bias results if missingness on the covariates is not missing at random. It is conceptually possible to use a multiple imputation to derive less biased estimates in the presence of missing data, but this has not yet been demonstrated with SAS PROC LTA.

Finally, the generalizability of the study findings may be limited. As noted earlier, the sample for this study was drawn from schools in three counties in North Carolina. Although the study had a very high participation rate across data collection waves and is therefore very representative of school-attending adolescents from these three counties, the population in these counties is more rural, has a higher proportion of racial/ethnic minorities, and is more economically disadvantaged than either the state of North Carolina or the United States. Therefore, the study findings should not be generalized beyond the three counties but instead should be viewed as a preliminary investigation from a relatively large, general population sample of adolescents that contributes to our overall understanding of the role inhalants may play in adolescent drug use sequencing.

6.3 Implications and Future Research

The results of this study provide initial evidence to suggest that white females, particularly those in the early years of middle school, are at an elevated risk for inhalant use initiation and, in a finding unique to this study, that this early use of inhalants is associated with an increased probability of transitioning to marijuana use. This finding is preliminary and needs to be replicated with other samples—particularly nationally representative

samples, larger samples, and samples that are young enough to allow for the identification of early stages of drug use initiation.

The gateway hypothesis remains a widely accepted model for drug use development and has served as a key rationale for prevention programming and drug use interventions. Despite cautions from developmental researchers, including proponents of the gateway hypothesis, there has been a tendency to assume that the gateway sequence represents a causal sequence. There is limited evidence to support this notion. Therefore, the primary utility of the gateway hypothesis may be to frame research on drug use sequencing. Using the general tenets of the gateway hypothesis, this study has demonstrated that for white females only, inhalant use may operate as a before-unidentified gateway drug, by both preceding and increasing the probability of transitioning to marijuana use. This study also demonstrated that the inclusion of covariates thought to represent antecedents of adolescent drug use substantially, although not fully, decreased the gateway relationship between inhalants and marijuana. Although the range of covariates examined was large, there are undoubtedly a number of variables related to drug use that were not included. Future research should attempt to better understand how contextual and individual characteristics influence the gateway drug use sequence.

This study demonstrated the utility and importance of separately analyzing the data based on gender and race. Replicating these analyses with other racial/ethnic groups (particularly Hispanic and Native American adolescents) is warranted, although as evidenced here, the samples need to be sufficiently large and should include young (6th grade or younger) adolescents. For this study, the 6th–7th grade transition period was clearly important for white females. However, a high percentage of white males had already initiated

drug use by this time. Even younger samples may be necessary to adequately explicate the early gateway drug use sequence.

The problem of recanting was illustrated in this study. Future longitudinal studies of adolescent drug use should be especially cognizant of this issue and should attempt to identify ways of improving response consistency among respondents and accounting for recanting in the analyses. LTA, a latent variable approach, provides a principled way of addressing this type of measurement error. However, given the especially high rates of recanting on the inhalants item, and for African American adolescents, it is possible that the results of this study are overly conservative. Certainly, the results for African American adolescents should be viewed cautiously given the very high measurement error. Effort should also be made by researchers to include detailed questions about inhalants rather than the more general questions typically used in national surveys. Misunderstanding of what substances the term "inhalants" include may in part explain higher rates of recanting relative to the gateway drugs.

Given recent trends suggesting that inhalant use is rising among white females (Substance Abuse and Mental Health Services Administration [SAMHSA], 2007) and that inhalants are the most commonly used illicit substance among young adolescents (e.g., Johnston et al., 2007), there is strong rationale for focusing prevention efforts on inhalants, a largely ignored substance in current prevention curricula. The traditional rationale for focusing prevention efforts primarily on alcohol, tobacco, and marijuana has been that these substances serve as gateways to more "serious" drug use; the finding that inhalants may operate as a partial gateway to marijuana use for white females transitioning from 6th to 7th

grade argues for an increased focus on inhalants in prevention programming, at least for white female adolescents.

Recent advances in LTA and LTA software allow for the inclusion of dichotomous and continuous covariates, greatly expanding the types of models that can be estimated. This study has demonstrated the utility of conducting LTA-with-covariates to examine the degree to which covariates (competing factors) explain drug use transition probabilities and thereby directly test the gateway hypothesis that the use of a gateway drug increases the probability of using illicit drugs. Given the ongoing debate between proponents of the gateway hypothesis and critics who argue for a common-cause explanation for drug use patterns, this approach should be considered to look at the more commonly described gateway transitions from alcohol and/or cigarettes to marijuana and from marijuana to hard drug use. As future enhancements to current LTA software are made, including Bayesian estimation to allow for the production of standard errors and subsequent hypothesis testing (Lanza et al., 2005), this approach holds great promise for testing the gateway hypothesis.

In sum, this study adds to a relatively small body of research on adolescent inhalant use. Inhalant use is a prevalent and serious issue for young adolescents, and evidence suggesting that inhalant use rates are remaining stable for U.S. adolescents, and even increasing for females, is cause for concern. Inhalants, like the other "gateway" drugs, are widely available and are often used early in adolescent development. This study, the first to examine directly where and how inhalant use fits within adolescent gateway drug use sequencing, has produced results suggesting that for white females, inhalant use is prevalent and is associated with an increased probability of transitioning to marijuana use, even after

controlling for factors thought to represent general liabilities for adolescent drug use. LTA is particularly well-suited to testing models that posit change in time for discrete stages.

APPENDICES

APPENDIX A
DESCRIPTIVE STATISTICS FOR COVARIATES

Covariate			**6th Grade Baseline**	**7th Grade Baseline**
Dichotomous Covariates	Code	Label	Frequency (Valid %)	Frequency (Valid %)
Social values	0	"Above average"	301 (65.3)	611 (70.1)
	1	"Below average"	160 (34.7)	261 (29.9)
	.	Missing	3	82
Grade point average	0	"Above average"	274 (61.0)	506 (57.8)
	1	"Below average"	175 (37.7)	369 (42.2)
	.	Missing	15	79
School attachment	0	"Above average"	229 (49.4)	411 (46.5)
	1	"Below average"	228 (49.1)	472 (53.5)
	.	Missing	7	71
Mother's disapproval of all drug use	0	Yes	412 (91.2)	751 (87.0)
	1	No	40 (8.8%)	112 (13.0)
	.	Missing	12	91
Religiosity	0	"Above average"	298 (65.6)	539 (61.7)
	1	"Below average"	156 (34.4)	335 (38.3)
	.	Missing	10	80
Perceived drug use at school	0	"Below average"	283 (62.9)	537 (61.4)
	1	"Above average"	167 (37.1)	338 (38.6)
	.	Missing	14	79
Any drug use, five closest friends	0	"0 or 1"	382 (82.9%)	695 (78.3)
	1	"> 1"	79 (17.1)	193 (21.7)
	.	Missing	3	66

Descriptive Statistics for Covariates (continued)

Covariate			6th Grade Baseline	7th Grade Baseline
Tolerant of any drug use, five closest friends	0	"0 or 1"	353 (76.7)	635 (71.9)
	1	"> 1"	107 (23.1)	248 (28.1)
	.	Missing	4	71
Perceived availability of drugs	0	"Below average"	280 (62.6)	507 (58.0)
	1	"Above average"	167 (37.4)	367 (42.0)
	.	Missing	17	80
Academic aspirations (importance of graduating high school and/or college)	0	"Important"	405 (88.4)	759 (87.1)
	1	"Not important"	53 (11.6)	112 (12.9)
	.	Missing	6	83
Problem behavior	0	"Below average"	307 (66.7)	601 (68.3)
	1	"Above average"	153 (33.3)	279 (31.7)
	.	Missing	4	74
Sensation seeking	0	"Below average"	246 (55.3)	470 (54.5)
	1	"Above average"	199 (44.7)	392 (45.5)
	.	Missing	19	92
Continuous Covariates[a]			6th Grade Mean (sd)	7th Grade Mean (sd)
Sensation seeking[b]			3.47 (3.33)	4.31 (3.67)
N			445	862
Missing			19	92

Descriptive Statistics for Covariates (continued)

Covariate		6th Grade Baseline	7th Grade Baseline
Age		11.97 (.45)	12.98 (.46)
	N	464	954
	Missing	0	0

[a] Continuous covariates are standardized.

[b] For white females in the 6th–7th grade sample, estimation with the binary sensation-seeking measure failed. Using the continuous version of the measure facilitated estimation. The binary version of the measure is used for the 7th–8th grade sample.

APPENDIX B
ODDS RATIOS FOR PREDICTORS OF STAGE MEMBERSHIP (Δ) AT BASELINE FOR WHITE FEMALES IN THE 6TH–7TH GRADE SAMPLE

	Latent Stage at Baseline					
Covariate	**No Use (N)**	**Alcohol (A)**	**Cigarettes (C)**	**Alcohol + Cigarettes (AC)**	**Alcohol + Cigarettes + Inhalants (ACI)**	**Alcohol + Cigarettes + Inhalants + Marijuana (ACM)**
Age	—	1.05	1.00	1.07	1.36	1.59
Social values	—	3.01	2.08	6.65	2.79	1,111.34
GPA	—	0.96	1.00	1.39	0.56	1.32
School attachment	—	1.79	3.94	1.98	0.44	13.41
Mother's disapproval of drug use	—	4.10	10.24	14.21	23.15	13.44
Religiosity	—	2.16	1.40	0.75	2.03	7.23
Perceived drug use at school	—	1.92	1.64	4.09	5.94	1,114.33
Any drug use, five closest friends	—	3.59	3.71	6.44	6.58	5,568.15
Tolerant of any drug use, five closest friends	—	3.90	7.17	12.49	73.02	5,787.13
Perceived availability of drugs	—	2.21	1.19	6.03	9.06	1,303.71
Academic aspirations	—	1.11	1.56	1.22	4.14	6.29
Problem behavior	—	1.56	2.59	2.79	5.72	4.50
Sensation seeking	—	2.09[a]	3.11[a]	2.31[a]	4.64[a]	5.00[a]

Note: Dashes (—) indicate reference category.

[a] To facilitate model convergence, sensation-seeking is treated as a continuous variable in the 6th–7th grade analyses; it is binary in the 7th–8th grade analyses.

APPENDIX C
ODDS RATIOS FOR PREDICTORS OF STAGE MEMBERSHIP (Δ) AT BASELINE FOR WHITE FEMALES IN THE 7TH–8TH GRADE SAMPLE

	Latent Stage at Baseline					
Covariate	**No Use (N)**	**Alcohol (A)**	**Cigarettes (C)**	**Alcohol + Cigarettes (AC)**	**Alcohol + Cigarettes + Inhalants (ACI)**	**Alcohol + Cigarettes + Inhalants + Marijuana (ACM)**
Age	—	0.96	1.04	1.09	1.02	1.21
Social values	—	3.13	0.33	4.18	11.63	13.71
GPA	—	0.85	0.95	1.68	2.33	1.87
School Attachment	—	1.34	0.82	2.40	3.66	3.27
Mother's disapproval of drug use	—	3.93	11.78	14.97	8.28	23.07
Religiosity	—	2.46	1.29	2.67	4.06	3.13
Perceived drug use at school	—	1.13	4.30	2.39	4.57	8.93
Any drug use, five closest friends	—	2.83	7.84	11.90	31.21	76.63
Tolerant of any drug use, five closest friends	—	3.29	3.12	12.08	20.50	107.29
Perceived availability of drugs	—	1.54	1.36	4.81	15.05	38.14
Academic aspirations	—	1.26	3.24	2.48	3.12	4.96
Problem Behavior	—	1.40	1.21	2.42	5.98	7.62
Sensation Seeking	—	2.45	3.41	7.56	22.16	22.19

Note: Dashes (—) indicate reference category.

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